ATLANTIC ZONE PROGRAMME

Report No. 37
Field Report No. 84

WEATHERING OF FLUVIAL DEPOSITS CONTAINING MATERIAL UNDER HUMID TROPICAL CONDITIONS

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CENTRO AGRONOMICO TROPICAL DE
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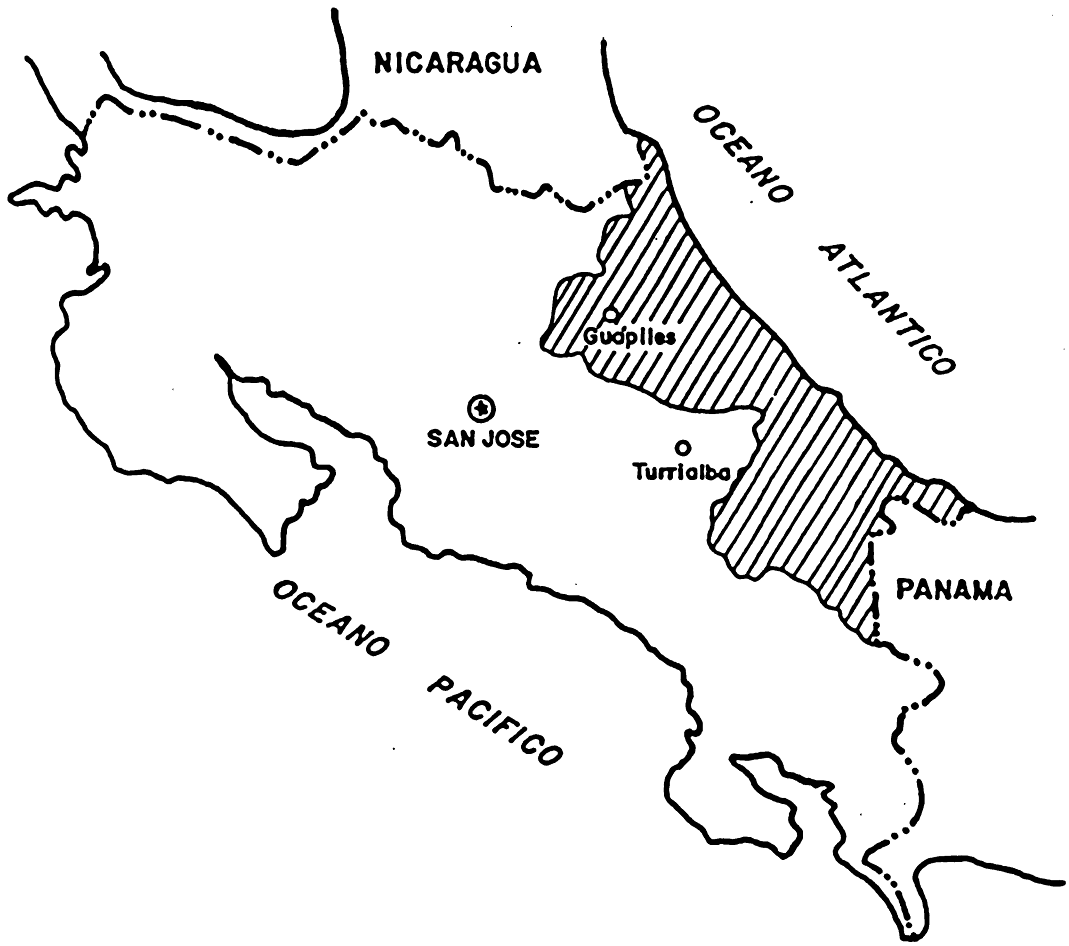

Location of the study area.

PREFACE

General description of the research programme on sustainable Landuse.

The research programme is based on the document "elaboration of the VF research programme in Costa Rica" prepared by the Working Group Costa Rica (WCR) in 1990. The document can be summarized as follows:
To develop a methodology to analyze ecologicaly sustainable and economically feasible land use, three hierarchical levels of analysis can be distinguished.
1. The Land Use System (LUS) analyses the relations between soil type and crops as well as technology and yield.
2. The Farm System (FS) analyses the decisions made at the farm household regarding the generation of income and on farm activities.
3. The Regional System (RS) analyses the agroecological and socio-economic boundary conditions and the incentives presented by development oriented activities.

Ecological aspects of the analysis comprise comparison of the effects of different crops and production techniques on the soil as ecological resource. For this comparision the chemical and physical qualities of the soil are examined as well as the polution by agrochemicals. Evaluation of the groundwater condition is included in the ecological approach. Criterions for sustainability have a relative character. The question of what is in time a more sustainable land use will be answered on the three different levels for three major soil groups and nine important land use types.

Combinations of crops and soils

	Maiz	Yuca	Platano	Piña	Palmito	Pasto	Forestal I II III
Soil I	x	x	x		x	x	x
Soil II						x	x
Soil III	x			x	x	x	x

As landuse is realized in the socio-economic context of the farm or region, feasibility criterions at corresponding levels are to be taken in consideration. MGP models on farm scale and regional scale are developed to evaluate the different ecological criterions in economical terms or visa-versa.

Different scenarios will be tested in close cooperation with the counter parts.

The Atlantic Zone Programme (CATIE-AUW-MAG) is the result of an agreement for technical cooperation between the Centro Agronómico Tropical de Investigación y Enseñanza (CATIE), the Agricultural University Wageningen (AUW). The Netherlands and the Ministerio de Agricultura y Ganadería (MAG) of Costa Rica. The Programme, that was started in April 1986, has a long-term objective multidisciplinary research aimed at rational use of the natural resources in the Atlantic Zone of Costa Rica with emphasis on the small landowner.

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SUMMARY

The Atlantic Zone of Costa Rica is dotted by small red coloured hills which consists of deeply weathered sediments. The deposits are probably of Pleistocene age and are the remnants of a Pleistocene landscape which was eroded by rivers during the last glacial period. A C-14 dating pointed out that one of them (Rio Sucio Profile, location see figure 4.1.) is older than 50,000 years.

Research was done in order to make a geological interpretation of the so-called "Redhill" - deposits and to study their weathering. The geochemical and mineralogical weathering studied was done in order to answer the following questions:

- What geochemical and mineralogical changes are taking place during weathering of these deposits;

- How do different types of sediment influence the weathering processes and the mineralogy and geochemistry of the deposits.

1. Introduction

The Atlantic Zone of Costa Rica is dotted by small red coloured hills which consists of deeply weathered sediments. The deposits are probably of Pleistocene age and are the remnants of a Pleistocene landscape which was eroded by rivers during the last glacial period. A C-14 dating pointed out that one of them (Rio Sucio Profile, location see figure 4.1.) is older than 50,000 years.

The deposits probably consist of fluvial and pyroclastic sediments. The parent material is supposed to be of andesitic composition since it is derived from the volcanic hinterland with mainly andestic volcanism.

The sediment are strongly weathered due to high annual rainfall (about 4000 mm), relatively high temperature (yearly average of 25oC) and their easy weatherability.

Research was done in order to make a geological interpretation of the so-called "Redhill" - deposits and to study their weathering. The geochemical and mineralogical weathering studied was done in order to answer the following questions:

- What geochemical and mineralogical changes are taking place during weathering of these deposits;

- How do different types of sediment influence the weathering processes and the mineralogy and geochemistry of the deposits.

2.Theory.

2.1.Weathering of andesitic material under humid tropical conditions

Weathering of andesitic volcanic material under humid tropical conditions is characterized by rapid degradation (by hydrolysis, oxidation and destruction of primary mineral structures (Colman, 1982)) of the primary minerals, mainly feldspars, pyroxenes and volcanic glass. Dissolution reactions can be written as follows:

$KAlSi_3O_8 + 4H^+ + 4H_2O \rightarrow K^+ + Al^{3+} + 3H_4SiO_4$ (aq)
(K-feldspar)

$CaFeSi_2O_6 + 4H^{+} + 2H_2O \rightarrow Ca^{2+} + Fe^{2+} + 2H_4SiO_4$ (aq)
(Augite)

The protons used for the reaction can be supplied by dissolved CO_2 in the soil solution.

Due to the usually strong leaching conditions in the humid tropics the liberated base-ions will almost completely be washed out.
The Fe^{2+} wich come into solution is first oxidized to Fe^{3+} and can precipitate as Fe(hydr)oxides, for instance the poorly ordered mineral ferrihydrite[1)].

The liberated Al^{3+} and part of the silica commonly precipitate in secondary minerals, for instance halloysite[2] and allophane.

Allpohane can be defined as a group of short-range ordered clay minerals that contain silica, alumina and water in chemical combination (Parfitt and Childs, 1988), and has usually a Al/Si-ratio between 1 and 2. Generally, allophane forms from glass (at pH(H_2O) 5 to 7) and feldspar and/of biotite (at pH(H20) about 5) in soils with udic moisture regimes and with good drainage. Under these conditions silicic acid and hydroxy-aluminium cations react to give allophane. A pH > 4.7 is requiered for allophane to precipitate Parfitt and Kimble, 1989). The formation of allophane can be (partly) prevented by the presence of humus, which can complex the liberated Al^{3+} (Mizota and van Reeuwijk, 1989).

Allophane seems to be formed by rapid weathering of Al- and Si-rich minerals, which results in relatively high concentrations of Al^{3+} and silica in the soil solution. The high concentrations probably cause a rapid precipitation of amorphous and poorly ordered hydrous alumino-silicates, mainly allophane. The exact mechanism of allophane formation has not been found in the literature.

With time allophane may be transformed to halloysite, kaolinite[3)] or gibbsite[4)] as well as 2:1 type clay minerals depending on the silica concentration of the soil solution (Wright, 1964). Halloysite may probably also be transformed to kaolinite, gibbsite or 2:1 clay minerals. Under humid conditions ferrihydrite can be transformed into goethite[5)]. See figure 2.1. for the stability relationships among some minerals in the system $K_2O-Al_2O_3-SiO_2-H_2O$ at 25°C.

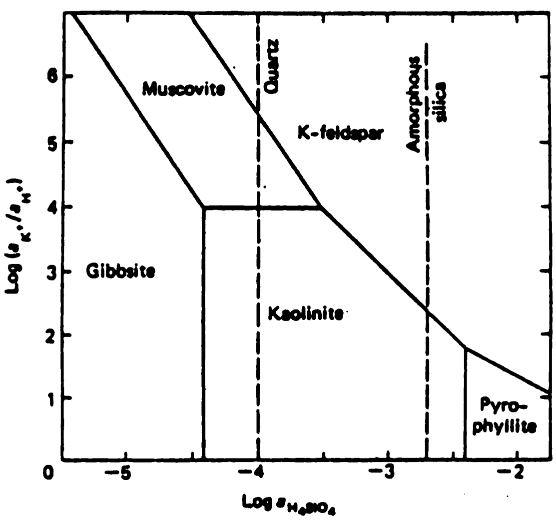

figure 2.1.: Stability relationships among some minerals in the system $K_2O-Al_2O_3-SiO_2-H_2O$ at 25°C (After Drever, 1988).

[1] ferrihydrite = approximately: $Fe_2O_3.2FeOOH.2*6H_2O$
[2] halloysite = $Al_4[Si_4O_{10}/OH)_2]*4H_2O$
[3] kaolinite = $Al_4[Si_4O_{10}/OH)_2]$
[4] gibbsite = $Al(OH)_3$
[5] goethite = Fe(OOH)

2.2.Dissolution rate.

An important process in weathering is dissolution of the primary minerals. Three processes can control the rate of dissolution of an inorganic solid phase (figure 2.2., after Drever, 1988):

1) Reaction at the surface of a mineral grain (reaction control), typically detachment of species at the mineral surface. When surface reaction is rate controlling, the concentrations of the solutes immediately adjacent to the grain will be the same as in the bulk solution.

2) Transport (normally by diffusion) of ions or molecules in solution to or from the grain surface (diffusion or transport control). In this case, the solution immediately adjacent to the solid will be more or less in equilibrium with the solid, and concentration gradients will exist in solution.

3) Diffusion of ions or molecules through a layer of solid reaction products or a layer of partly altered primary mineral surrounding the solid. For many purposes this can be regarded as a type of surface reaction control; it will result in a uniform solution composition.
Mixed kinetics (partly diffusion controlled, partly reaction controlled) may also occur, but generally either diffusion or

reaction is the dominant control, and the other can be neglected. (after Drever, 1988).

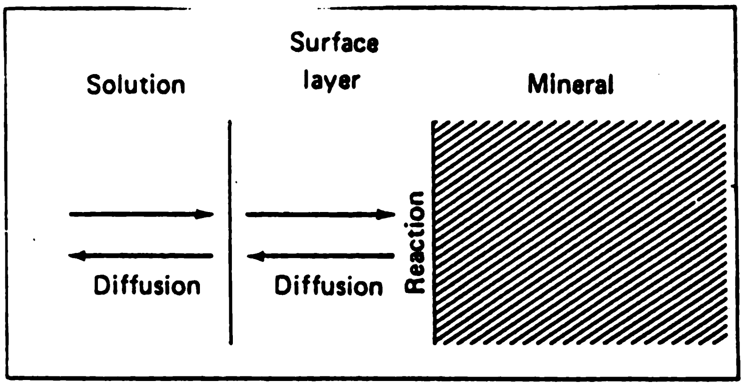

Figure 2.2: Schematic drawing of a mineral reacting with solution. The rate determining step may be reaction at the surface of the mineral, diffusion through a solid layer at the grain surface, or diffusion in solution.

3.Methods.

3.1.Field descriptions.

In order to describe the 'Redhill'-deposits four geographically separated locations, three roadcuts and a canalcut, were selected. At each location a profile of about 6 meters deep was chosen for detailled description. For these descriptions the profiles were divided into several layer-types, mainly on a textural and geological basis, varying in thickness between between 5 and 200cm. The most important soil-characteristics and the geology of each layer were described. Depending their texture and deposition mechanism (according to the field descriptions) the layers were grouped into five classes, the strongly altered topsoil fell into class 0.

3.2.Sampling procedures.

All layers of the four profiles were sampled by taking representative field moist mixed samples (each about 500 g) from the centre of the layers. If the layer was thicker than 100cm two samples were taken, one in the upper part and one in the lower part. In total about 50 samples were collected.

3.3.Analytical procedures.

Texture was determined after destruction of organic matter in the field moist sample with H_2O_2 and dispersion using a mixture of sodium polymetaphosphate and NH_3. Clay and silt (2 - 53 micrometer) contents were measured by the hydrometer method (Gee and Bauder, 1986). After the measurement, the suspensions with clay and silt were discarded, and the remaining samples were dried and passed over a nest of sieves, in order to determine weight percentages of the fractions >2mm, 2mm-500µm, 500-212µm and 212-53µm. Clay dispersion of weathered volcanic material is often difficult. Texture analysis are probably relatively reliable since much attention was paid to the dispersion of the sample.

The bulk chemical composition (major elements and selected trace elements) was determined by X-ray fluorescence. After ignition at 900°C to determine contents of crystalline water plus organic matter, glass tablets were obtained by melting the samples with 2.4 lithium tetraborate and analysed on a Philips XRF assembly. Major oxide components were normalized to 100%. FeO is measured as Fe_2O_3.

Mineralogy of the clay fraction, collected after texture analysis, was determined by X-ray diffraction, after saturation of the clay minerals with Mg^{2+}. The samples were scanned in wet condition and after drying at 25° and 100°C.

Acid ammonium oxalate extractable iron and aluminium (Fe_{ox} and Al_{ox} were determined by shaking a 1 g soil air dry /100 ml reagent solution for 4 h in the dark (Blackmore et al., 1987) and measuring Fe and Al by AAS.

3.4. Weathering indices.

Weathering indices were calculated in order to study changes in geochemistry due to weathering processes. The weathering potential index (WPI) and the product index (PI) (after Reiche, 1950) were used:

$$WPI = 100* \ \Sigma Bases / (\Sigma Bases + SiO_2 + \Sigma R_2O_3)$$

$$PI = 100* \ SiO_2 / (SiO_2 + \Sigma R_2O_3)$$

For the calculation of the indices the molair fractions of the elements were used. MgO, CaO, K_2O and Na_2o were grouped as total bases; Al_2O_3, TiO_2 and Fe_2O_3 were grouped as R_2O_3.

The WPI is a measure for the amount of base-ions in the sample. The WPI of an average andesite is about 18.3. The WPI rapidly decreases if bases are lost.
The PI is a measure for the amount of Si in the samples. The PI of an average andesite is about 78.9. If silica is lost the PI decre-ases.
R_2O_3 functions as a reference constituent, since it is supposed to be the least mobile component in the soil.

Fresh sediment samples from the Río Chirripo (by van Seeters, 1992) function as an indicator for the chemical composition of the primary sediments of the 'Redhill'-deposits.

4.Site descriptions

The locations of the four profiles is shown in figure 4.1.

4.1.Río Frío Uno profile:

The profile consists of a sequence of sandy and silty to clayey deposits, which are probably of fluvial origin.
The texture of the individual layers and the alteration of fine and coarse textured layers would suggest that they are floodplain sediments. The sandy layers could be crevasse splays, while the silty and clayey layers could represent more finely grained floodplain accumulations.

It was not possible to determine the parent material of the upper two meters of the profile because of strong alteration by weathering processes and homogenisation by soil fauna. No burried soils were found which suggests that there was no appreciable weathering during deposition of the sediments.

4.2.Río Frío Dos profile:

The profile consists mainly of coarse sandy deposits with pebblerich layers, probably of fluvial origen.
Their coarse texture and crossbedding structures suggests that the deposits are in-channel sediments of a river.

It was not possible to determine the parent material of the upper 150 cm of the profile because of alteration by weathering processes and homogenisation by soil fauna. No burried soils were found which suggests that there was no appreciable weathering during deposition of the sediments.

4.3.Río Sucio profile:

The profile consists of a sequence of sandy and silty to clayey deposits, probably fluvial.
The texture of the individual layers and the alteration of fine and coarse textured layers would suggest that they are floodplain sediments, consisting of sandy crevasse splays and probably small streambeds, and fine grained floodplain accumulations. The lowest fine grained layer in the profile contains much organic matter and may represent a backswamp environment.

It was not possible to determine the parent material of the upper 130 cm of the profile because of alteration by weathering processes and homogenisation by soil fauna. No burried soils were found which suggests that there was no appreciable weathering during deposition of the sediments.

4.4.Neguev profile:

The profile consists of different types of sediments; sandy, pebble-rich and silty to clayey deposits and two very poorly sorted layers with a clayey to coarse texture containing pebbles. The two poorly sorted layers are probably lahars. On top of these layerst lies a silty to clayey sediment which could be pyroclatic deposit or a fluvial floodplain accumulation.

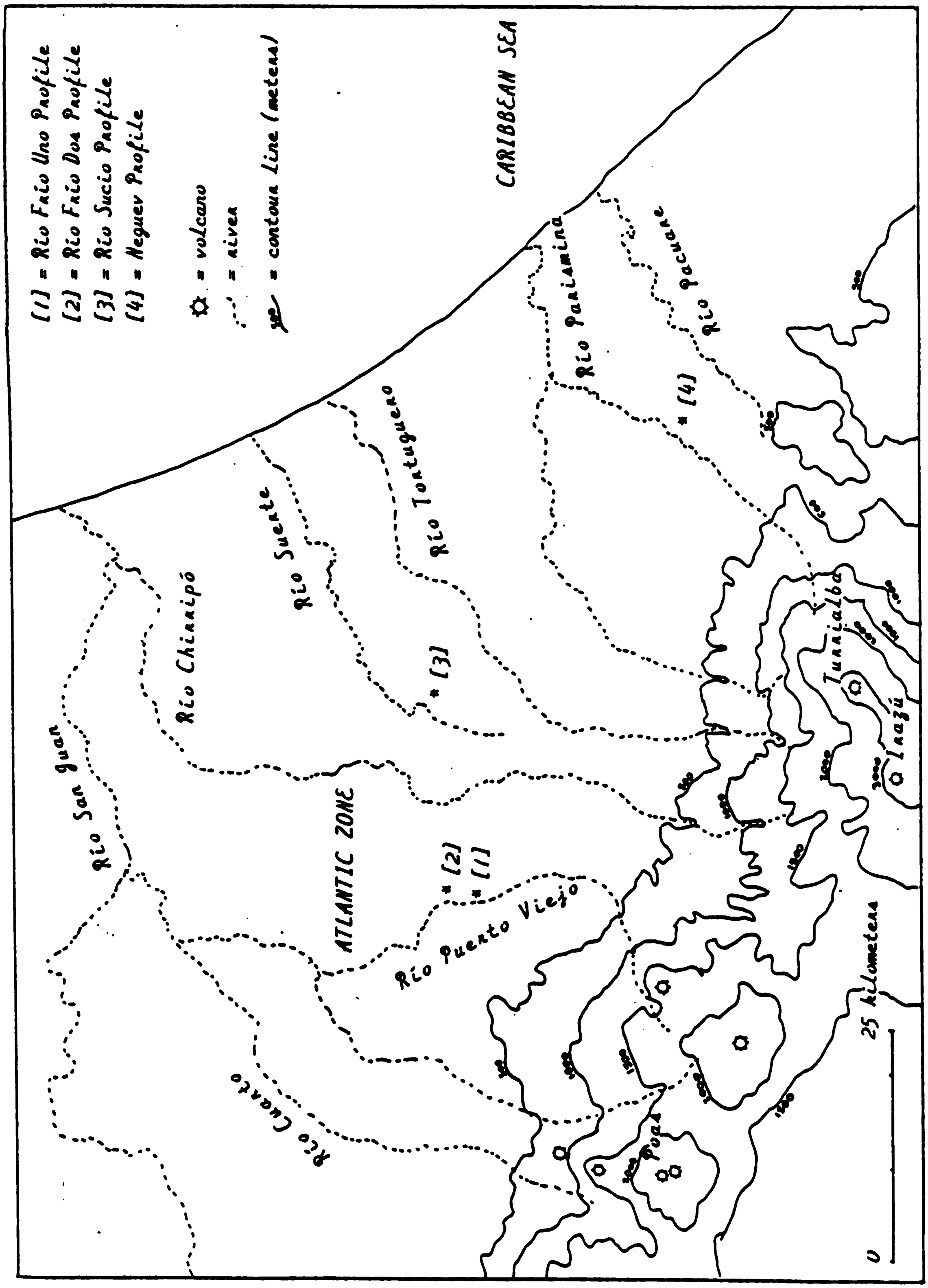

figure 4.1: Locations of the four sampled profiles.

The other sediments in the profile are probaly fluvial. The sandy layers can be in-channel sediments of small streams, the silty to clayey sediment is probably a floodplain deposit.

It was not possible to determine the parent material of the upper 60 cm of the profile because of alteration by weathering processes and homogenisation by soil fauna. No burried soils were found which suggests that there was no appreciable weathering during deposition of the sediments.

4.5. Classification of the sediment-types

The different sediment-types are grouped into the following classes (named layer-type 0 t/m 4):

Layer-type 0: Strongly altered top soil;
Layer-type 1: Silty and clayey sediments;
Layer-type 2: Sandy sediments;
Layer-type 3: Coarse grained pebble sediments;
Layer-type 4: Poorly sorted sediments (probably lahars).

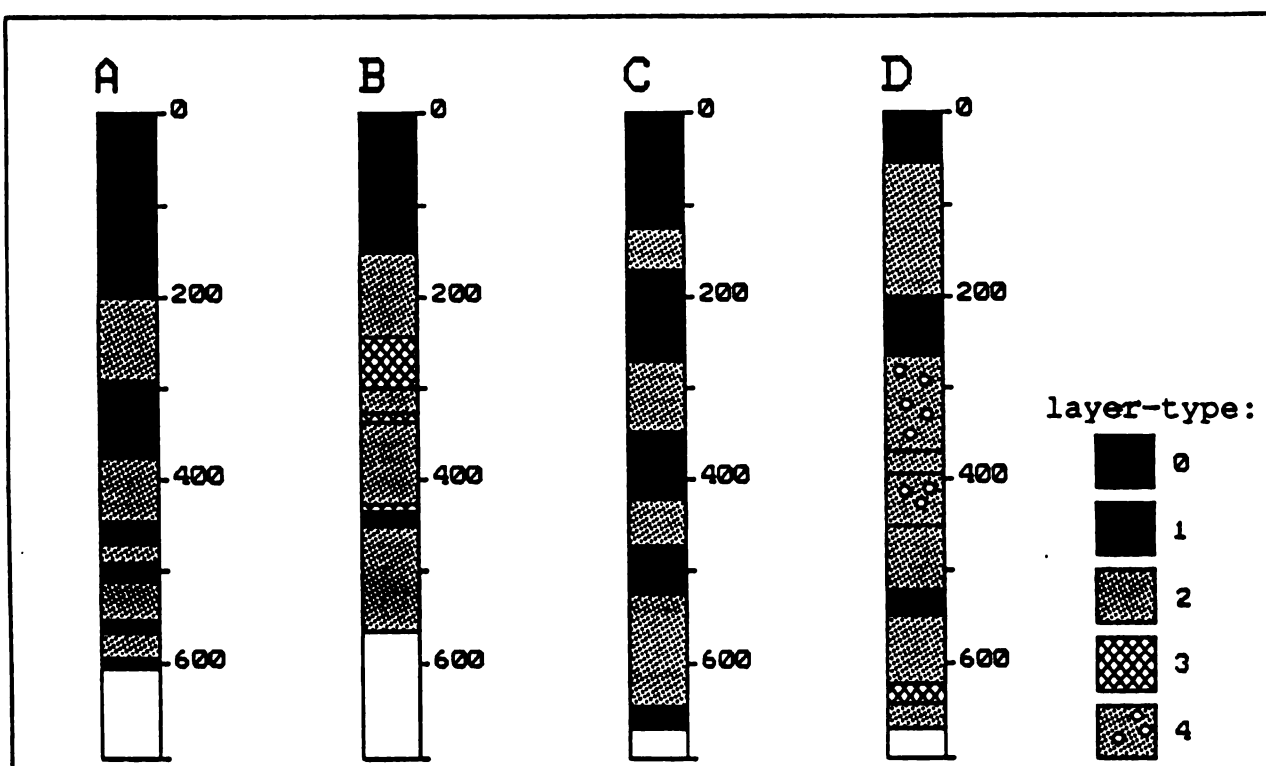

figure 4.2: Layer-types in the four profiles; A= Río Frío Uno Profile, B= Río Frío Dos Profile, C=Río Sucio Profile, D= Neguev Profile.

5.Results

5.1.Texture and mineralogy.

5.1.1.Río Frío Uno profile:

Sample	Depth cm	Layer-type	Clay	Aratio	Al_{ox}	Fe_{ox}	Gibb.	Crist.
A1	50	0	58	0.8	0.36	0.34	3	1
A2	150	0	57	2.2	0.42	0.43	3	1
B	245	2	27	6.5	0.43	0.49	3	2
C	330	1	38	2.9	0.30	0.13	0	1
D	410	2	9	3.2	0.40	0.38	2	2
E	460	1	33	2.9	0.29	0.11	0	1
F	480	2	6	8.5	0.40	0.07	1	3
G	500	1	45	1.9	0.40	0.06	0	1
H	530	2	11	8.5	0.34	0.28	0	3
I	550	1	-	-	-	-	-	-
J	575	2	6	-	0.29	0.17	-	-
K	600	1	36	2.0	0.45	0.19	0	1

Table 5.1.: **Mineralogy of the clay fraction and clay content of Río Frío Uno Profile.**
Clay-, Al_{ox}- and Fe_{ox}-content in mass fraction %.
Gibb. = Gibbsite, Crist. = Cristobalite; Content in sample: 3= much, 2=intermediate, 1=little, 0=nil, '-'= not analysed.
Aratio = 1.0nm clay minerals/ 0.7nm clay minerals.

The clay content decreases with depth from 58% in the top soil to 6% for layer-type 2 at 575 cm depth and 36% for layer-type 1 at 600 cm depth. The clay content of layer-type 1 is higher than that of layer-type 2 (figure 5.1.).

The crystalline clay fraction mainly consists of 1.0nm-halloysite and 0.7nm-halloysite or kaolinite, gibbsite and cristobalite. Little goethite and quartz is present. In the topsoil some 2:1 clay minerals were detected.

The Aratio (which is the ratio between the peak height of the 1.0 nm clay and the 0.7nm clay in the X-ray-diffractograms) increases with depth for layer-type 0 and 2 from 0.8 to 8.5. The ratio of layer-type 1 seems to decrease with depth from 3 to 2.
The amount of gibbsite deceases with depth. In layer-type 0, the topsoil, most gibbsite occurs. Layer-type 2 contains more gibbsite than layer-type 1.
The amount of cristobalite increases with depth, the content of layer-type 2 is higher than that of layer-type 1.

Al_{ox}-content is relatively low throughout the profile, between 0.30 and 0.45 %.

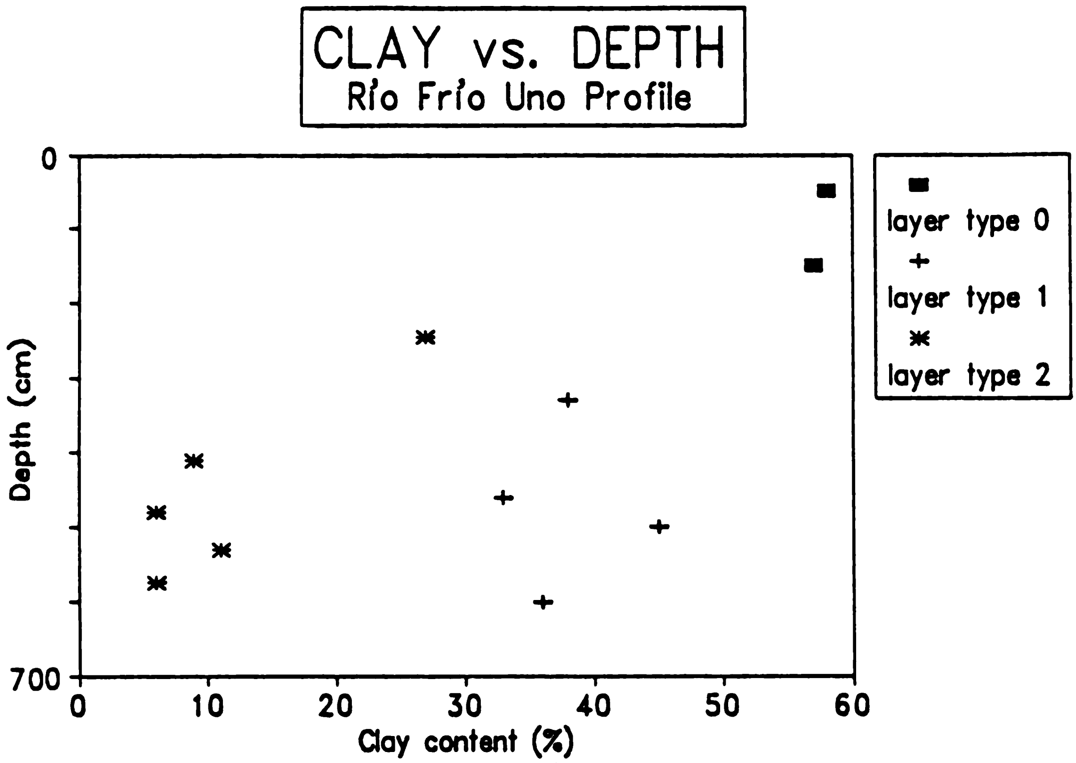

figure 5.1: Clay content versus depth, Río Frío Uno Profile.

5.1.2. Río Frío Dos profile:

Sample	Depth cm	Layer-type	Clay	Aratio	Al_{ox}	Fe_{ox}	Gibb.	Crist.
A1	50	0	53	0.6	0.44	0.37	3	1
A2	125	0	56	3.0	0.40	0.72	3	0
B	195	2	22	2.0	0.80	0.51	3	2
C	270	3	3	3.0	4.85	0.48	1	3
D	315	2	5	0.0	4.40	0.38	0	0
E	335	3	5	0.0	5.80	0.37	1	1
F	380	2	3	0.0	3.25	0.32	0	0
G	425	3	-	-	-	-	-	-
H	430	1	23	10	0.22	0.40	0	2
I	480	2	5	-	2.20	0.30	0	3
J	550	2	0	2.0	3.90	0.10	0	0

Table 5.2.: Mineralogy of the clay fraction and clay content of Río Frío Dos Profile.
Clay-, Al_{ox}- and Fe_{ox}-content in mass fraction %.
Gibb. = Gibbsite, Crist. = Cristobalite; Content in sample: 3=-much, 2=intermediate, 1=little, 0=nil, '-'= not analysed.
Aratio = 1.0nm clay minerals/ 0.7nm clay minerals.

The clay content decreases with depth from about 55% in the top soil to 0% for layer-type 2 at 550 cm depth. Clay content of layer-type 1 is higher than that of layer-type 2 which is higher than that of layer-type 3.

The crystalline clay fraction mainly consists of 1.0nm-halloysite and 0.7nm-halloysite or kaolinite, gibbsite and cristobalite. Little goethite and quartz is present. In the topsoil few 2:1 clay minerals are detected.

The Aratio (which is the ratio between the peak height of the 1.0 nm clay and the 0.7nm clay in the X-ray-diffractograms) does not seem to be correlated with depth and varies between 0.0 and 3.0 for layer-type 0, 2 and 3 and is 10.0 for layer-type 1 at 430 cm depth. Whenever the ratio is 0.0, the clay fraction does not contain crystalline clay minerals.
The amount of gibbsite deceases rapidly with depth, with layer-type 3 always containing more gibbsite than an underlying layer-type 2.
The distribution of cristobalite increases throughout the profile is very irregular.

Al_{ox}-content is relatively high in coarse textured layers that occur deeper than 250 cm. It varies between 2.20 and 5.80 %. The Al_{ox}-content in layer-type 3 is higher than that in type 2.

5.1.3. Río Sucio profile:

Sample	Depth cm	Layer-type	Clay	Aratio	Al_{ox}	Fe_{ox}	Gibb.	Crist.
A	30	0	76	1.4	0.45	0.42	1	1
B	95	0	65	2.0	0.26	0.24	1	1
C	150	2	26	2.7	1.75	0.38	2	1
D	175	1	67	6.0	0.40	0.07	1	1
E	205	1	59	7.3	0.36	0.09	0	0
F	250	1	35	7.4	0.40	0.10	0	0
G	310	2	17	11	0.38	0.48	0	1
H	385	1	27	7.7	0.32	0.20	0	0
I	445	2	18	13	0.48	0.46	0	0
J	500	1	36	32	0.40	0.34	1	1
K	540	2	8	–	0.47	0.68	–	–
L	570	2	9	18	0.52	0.90	0	2
M	615	2	4	13	0.45	0.47	0	2
N	660	1	13	18	0.24	0.30	0	1

Table 5.3.: **Mineralogy of the clay fraction and clay content of Río Sucio Profile.**
Clay-, Al_{ox}- and Fe_{ox}-content in mass fraction %.
Gibb. = Gibbsite, Crist. = Cristobalite; Content in sample: 3=much, 2=intermediate, 1=little, 0=nil, '-'= not analysed.
Aratio = 1.0nm clay minerals/ 0.7nm clay minerals.

Clay content decreases with depth from 76% in the top soil to 4% for layer-type 2 at 615 cm depth and 13% for layer-type 1 at 660 cm depth. Clay content of layer-type 1 is higher than that of layer-type 2 (see figure 5.2.).

The crystalline clay fraction mainly consists of 1.0nm-halloysite and 0.7nm-halloysite or kaolinite, gibbsite and cristobalite. little goethite and quartz is present.

The Aratio increases with depth from 1.4 in the top soil to about 18.3 at 660 cm depth. One very high value of 32.0 occurs at 500 cm depth. The Aratio for layer-type 1 does not differ systematically from that of layer-type 2.

The amount of gibbsite decreases with depth and is relatively low. The amount of cristobalite does not seem to vary systematicly with depth.

Al_{ox}-content is relatively low throughout the profile, less than 0.52 %, except for sample C which contains 1.75 %.

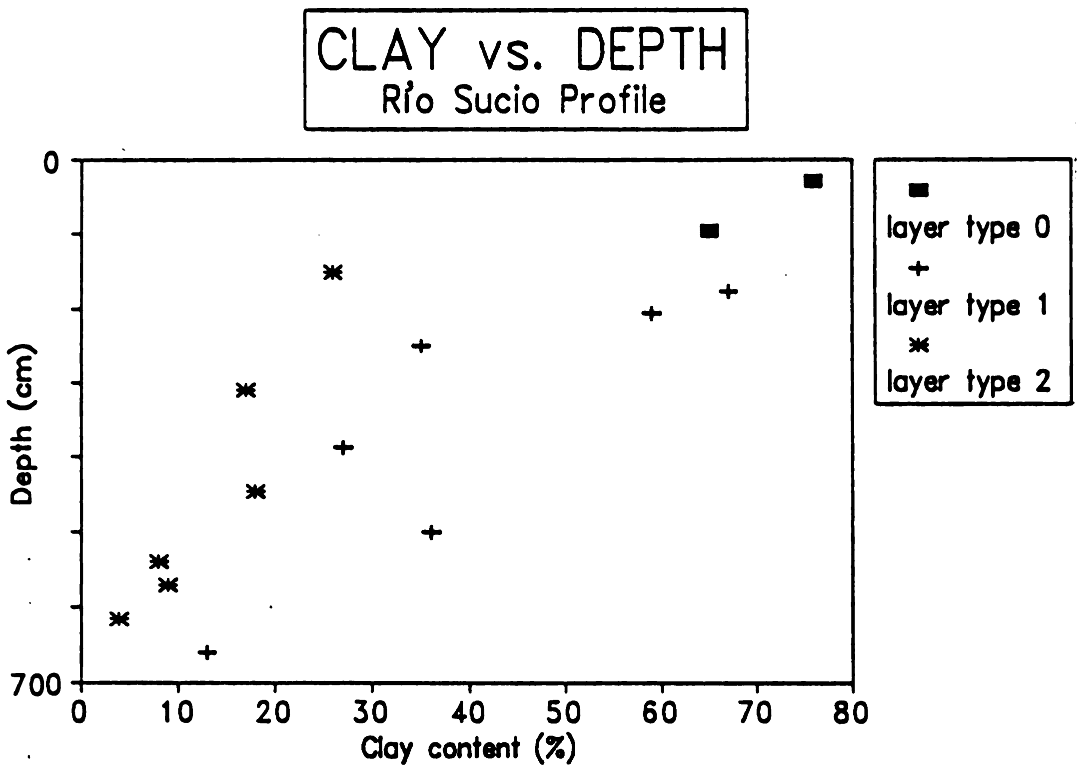

figure 5.2: Clay content versus depth, Río Sucio Profile.

5.1.4. Neguev profile:

Sample	Depth cm	Layer-type	Clay	Aratio	Al_{ox}	Fe_{ox}	Gibb.	Crist.
A	30	0	49	1.0	0.44	0.66	3	0
B	85	2	18	1.3	2.15	1.25	2	0
C	145	2	-	-	19.70	1.10	-	-
D	190	2	-	-	7.30	1.30	-	-
E	235	1	20	12	0.45	0.48	0	1
F	315	4	10	6.3	0.27	0.32	0	2
G	375	2	20	3.0	0.50	0.25	0	1
H	425	4	12	4.1	0.26	0.30	0	3
I	490	2	14	7.2	0.23	0.50	0	3
J	535	1	49	10	0.50	2.60	0	1
K	570	2	10	9.8	0.94	0.51	0	2
L	610	2	8	-	4.60	0.23	-	-
M	635	3	7	24	1.30	0.81	1	2
N	655	2	10	15	0.45	0.56	0	2

Table **5.4.: Mineralogy of the clay fraction and clay content of Neguev Profile.**
Clay-, Al_{ox}- and Fe_{ox}-content in mass fraction %.
Gibb. = Gibbsite, Crist. = Cristobalite; Content in sample: 3=-much, 2=intermediate, 1=little, 0=nil, '-'= not analysed.
Aratio = 1.0nm clay minerals/ 0.7nm clay minerals.

The clay content decreases with depth from 49% in the top soil to about 10% at 650 cm depth. Sample J contains relatively much clay. Clay content of layer-type 3 and 4 seems to be lower than that of layer-type 1 and 2.

The crystalline clay fraction mainly consists of 1.0nm-halloysite and 0.7nm-halloysite or kaolinite, gibbsite and cristobalite. Little goethite and quartz is present.

The Aratio increases with depth from 1.0 in the topsoil to 24.0 for layer-type 3 at 635 cm depth and 15.0 for layer-type 2 at 655 cm depth.
The amount of gibbsite rapidly decreases with depth.
The amount of cristobalite increases with depth and is higher for layer-types 2, 3 and 4 than for layer-type 1.

Al_{ox}-content is relatively high, higher than 1.0 % for five samples. Samples C and D have very high values, 19.70 and 7.30 %.

5.2. Chemistry.

5.2.1. Río Frío Uno profile:

Sample	Depth cm	Layer-type	ΣR_2O_3	SiO_2	ΣBases	WPI	PI
A1	50	0	42.4	56.8	0.5	0.5	57.2
A2	150	0	45.5	53.7	0.5	0.5	54.2
B	245	2	48.0	50.8	0.7	0.7	51.4
C	330	1	28.2	70.7	1.0	1.0	71.5
D	410	2	31.8	67.2	0.7	0.7	67.9
E	460	1	27.2	71.7	0.9	0.9	72.5
F	480	2	29.2	69.8	0.7	0.7	70.5
G	500	1	25.6	72.8	1.4	1.4	74.0
H	530	2	30.6	68.0	1.0	1.0	69.0
I	550	1	23.7	74.8	1.3	1.3	76.0
J	575	2	28.1	70.7	0.9	0.9	71.6
K	600	1	27.9	70.5	1.4	1.4	71.7
Fresh sediment:		1				11.8	78.9
		2				18.1	81.1

Table 5.5.: **Analyse results of profile Río Sucio. ΣR_2O_3, SiO_2 and ΣBases in molair fraction %. Fresh sediment data from van Seeters, 1992.**

The samples consists for the major part of the oxides of the elements Al, Fe and Si. In the topsoil the ΣR_2O_3 content is about 45 % (Al_2O_3 = 35 %, Fe_2O_3 = 9 % and TiO_2 = 1%) and it decreases to about 25 % (Al_2O_3 = 20 %, Fe_2O_3 = 5 % and TiO_2 = 0.6%) at 550 cm depth. SiO_2 content increases from about 55 % in the top soil to 70 % at greater depth. Throughout the profile the base-ion content is very low, lower than 1.5 %.

The WPI increases with depth from 0.50 in the topsoil to 0.96 for layer-type 2 and 1.36 for layer-type 1. The WPI of layer-type 1 is higher than that of type 2 (see figure 5.3.).

The PI first decreases from 57.2 in the top soil to 51.4 in the first layer-type 2 layer beneath the top soil at 245 cm depth, and then increases to 71.6 at 600 cm depth. The PI of layer-type 1 is higher than that of type 2 (see figure 5.4.).

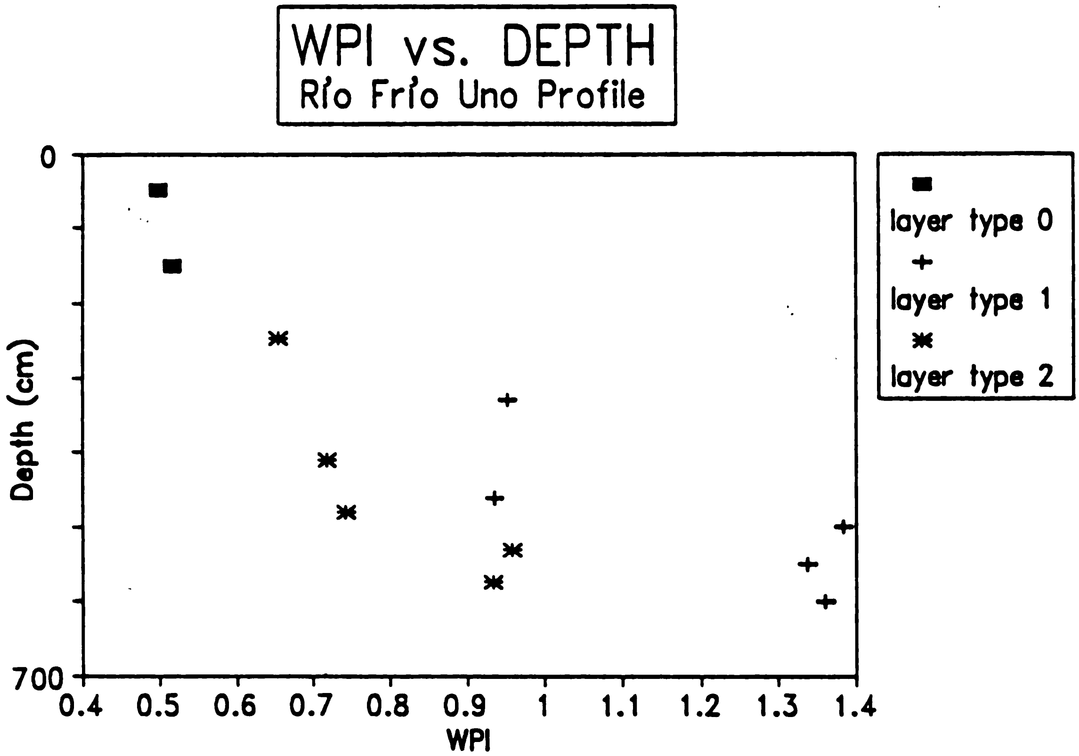

figure 5.3: WPI versus depth, Río Frío Uno Profile.

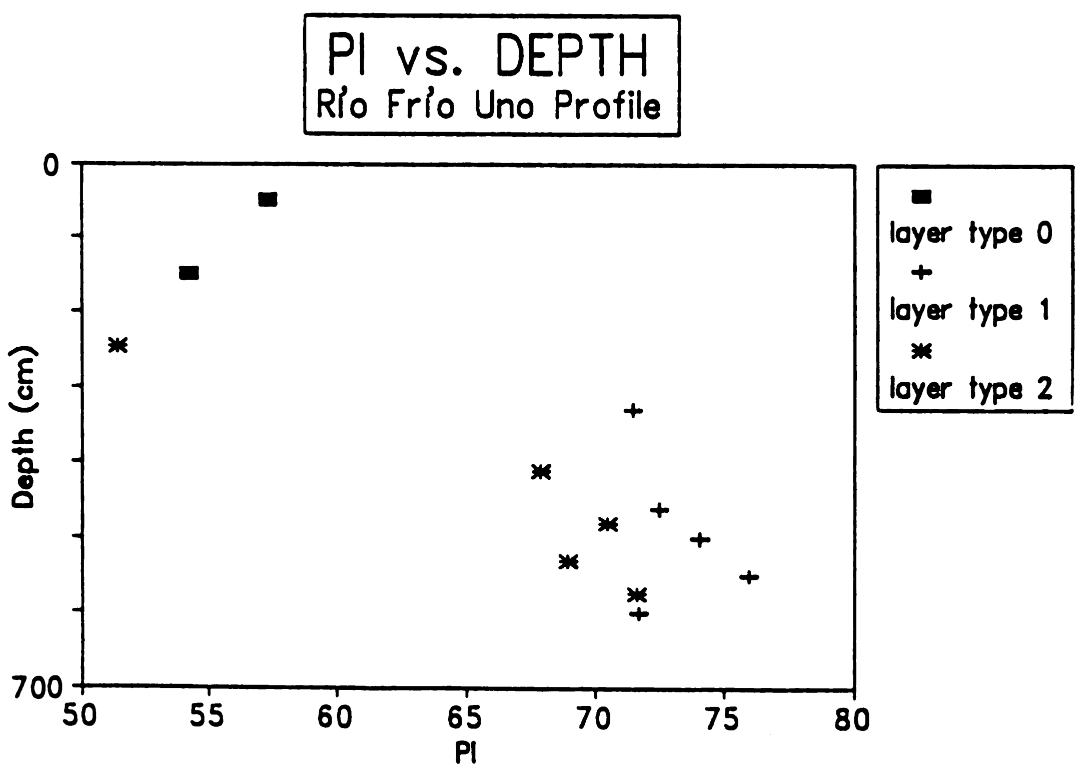

figure 5.4: PI versus depth, Río Frío Uno Profile.

5.2.2.Río Frío Dos profile:

Sample	Depth cm	Layer-type	ΣR_2O_3	SiO_2	ΣBases	WPI	PI
A1	50	0	46.7	52.3	0.6	0.6	52.8
A2	125	0	50.4	48.9	0.4	0.4	49.3
B	195	2	54.4	44.1	1.0	1.0	44.8
C	270	3	33.1	57.1	9.1	9.1	63.3
D	315	2	23.2	66.3	10.1	10.1	74.1
E	335	3	27.8	62.5	8.8	8.8	69.2
F	380	2	21.4	65.4	12.8	12.8	75.3
G	425	3	30.8	63.5	2.5	2.5	67.4
H	430	1	29.4	68.8	1.3	1.3	70.1
I	480	2	23.7	68.1	7.8	7.8	74.2
J	550	2	21.1	61.8	16.8	16.8	74.5
Fresh sediment:		1				11.8	78.9
		2				18.1	81.1

Table 5.6.: **Analyse results of profile Río Sucio.**
ΣR_2O_3, SiO_2 and ΣBases in molair fraction %.
Fresh sediment data from van Seeters, 1992.

The samples consists for the major part of the oxides of the elements Al, Fe, Si and at a greater depth than 200 cm also of the base-cations. In the topsoil the ΣR_2O_3 content is about 50 % (Al_2O_3 = 37 %, Fe_2O_3 = 12 % and TiO_2 = 1%) and it decreases to about 21 % (Al_2O_3 = 16 %, Fe_2O_3 = 5 % and TiO_2 = 0.5%) at 550 cm depth. SiO_2 content increases from about 48 % in the top soil to 68 % at greater depth. Content of base-cations is in the upper two meters of the profile very low, beneath this depth it is very high and varies between 1.3 and 16.8 % (at 550 cm). ΣBases is mainly determined by the quantity of MgO.

The WPI strongly increases with depth from about 0.5 in the top soil to 16.8 at 550 cm depth. The WPI of layer-type 2 seems to be higher than that of type 3 (see figure 5.5.).

The PI first decreases with depth from 52.8 in the topsoil to 44.8 in the first layer-type 2 layer beneath the topsoil at 195 cm, then it rapidly increases to 74.5 for layer-type 2 at 550 cm depth. The index seems to be higher for layer-type 2 than for that of 3 (see figure 5.6.).

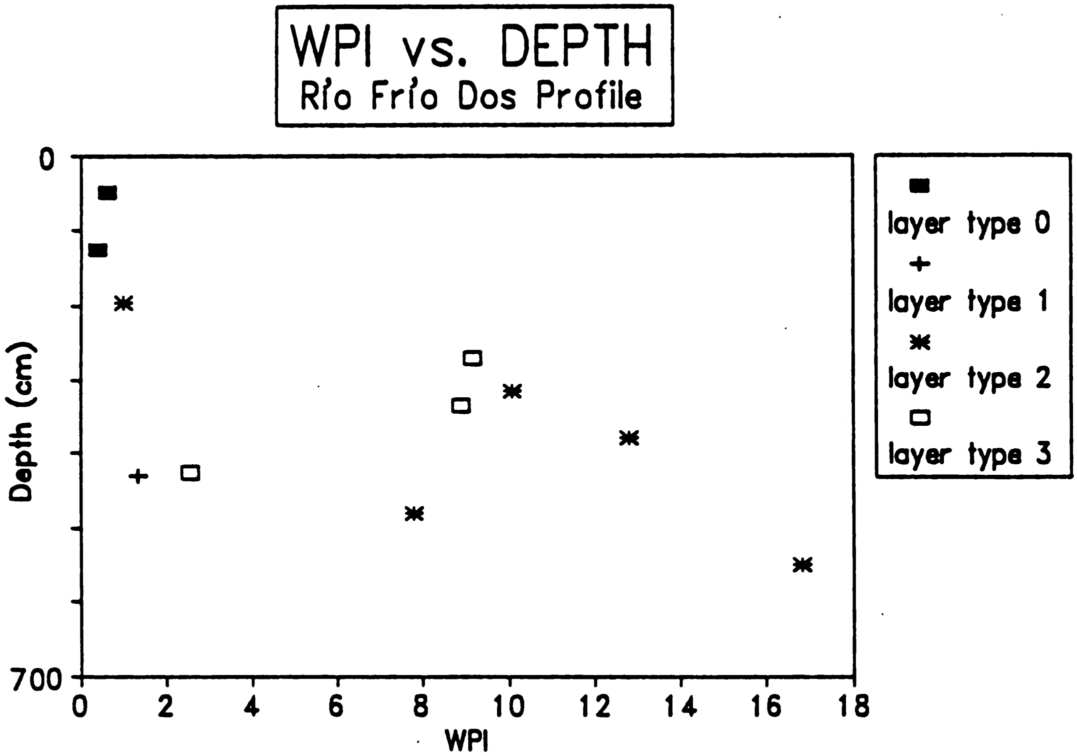

figure 5.5: WPI versus depth, Río Frío Dos Profile.

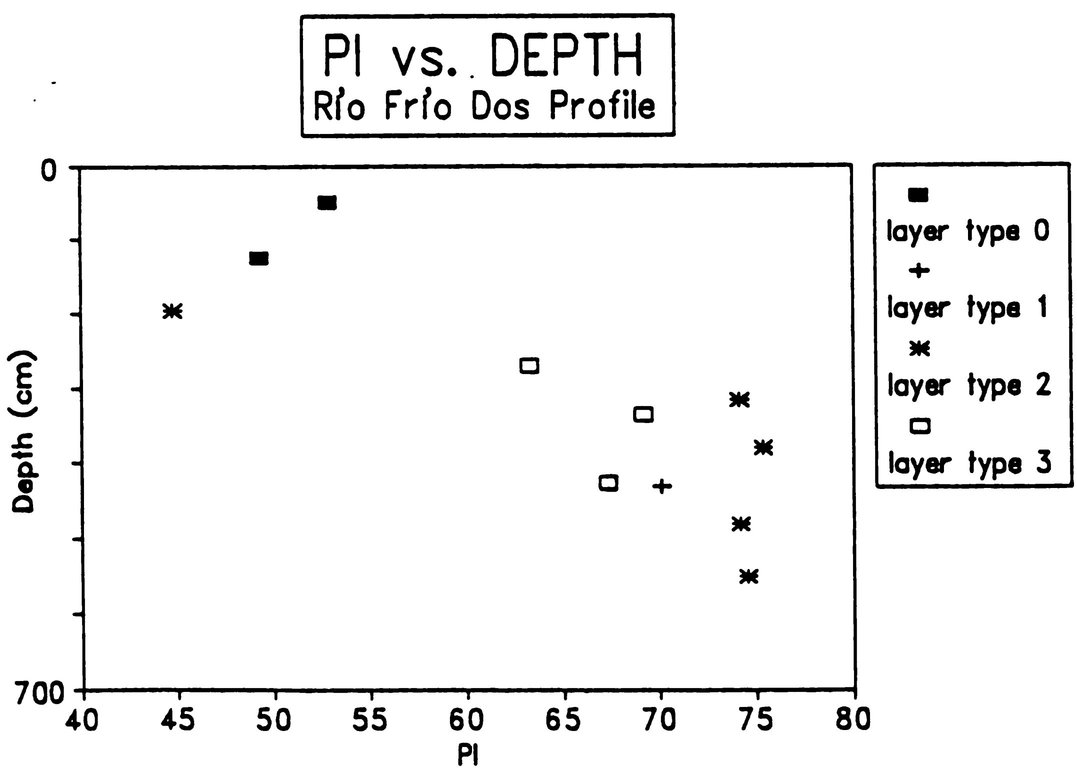

figure 5.6: PI versus depth, Río Frío Dos Profile.

5.2.3. Río Sucio profile:

Sample	Depth cm	Layer-type	ΣR_2O_3	SiO_2	ΣBases	WPI	PI
A	30	0	35.4	63.2	1.0	1.0	64.1
B	95	0	35.3	64.0	0.4	0.4	64.5
C	150	2	47.9	48.1	3.3	3.4	50.1
D	175	1	35.9	63.7	0.3	0.3	64.0
E	205	1	32.7	66.2	1.0	1.0	66.9
F	250	1	35.9	63.7	0.3	0.3	63.9
G	310	2	35.3	64.0	0.4	0.4	64.4
H	385	1	35.7	63.8	0.2	0.2	64.2
I	445	2	38.2	60.7	0.5	0.5	61.4
J	500	1	33.9	65.5	0.3	0.3	65.9
K	540	2	34.0	65.0	0.5	0.5	65.7
L	570	2	34.7	63.8	1.0	1.0	64.8
M	615	2	34.5	64.4	0.6	0.6	65.1
N	660	1	32.4	67.6	0.8	0.8	67.2
Fresh sediment:		1				11.8	78.9
		2				18.1	81.1

Table 5.7.: **Analyse results of profile Río Sucio. ΣR_2O_3, SiO_2 and ΣBases in molair fraction %. Fresh sediment data from van Seeters, 1992.**

The samples consists for the major part of the oxides of the elements Al, Fe and Si. In the topsoil the ΣR_2O_3 content is about 35 % (Al_2O_3 = 26 %, Fe_2O_3 = 8 % and TiO_2 = 1%) and it varies throughout the profile between 32 and 38 %, excepth for the high value just beneath the topsoil. SiO_2 content varies between 60 and 68 %, except for a low value for again the layer just beneath the top soil. Throughout the profile the base-ion content is very low, generally lower than 1.5 %.

The WPI first seems to decrease with depth from 1.0 in the top soil to about 0.3 at 350 cm depth, except for the high value at 150 cm depth. Then the WPI increases to about 0.8 for layer-type 1. The index of layer-type 1 seems to be slightly higher than that of layer-type 2 (see figure 5.7.).

The PI slightly increases with depth from 64.1 in the top soil to about 65.0 for layer-type 1 at 660 cm depth, except for the layer-type 2 layer just beneath the top soil which has a low value of 50.1. The PI of layer-type 1 is higher than that of layer-type 2 (see figure 5.8.).

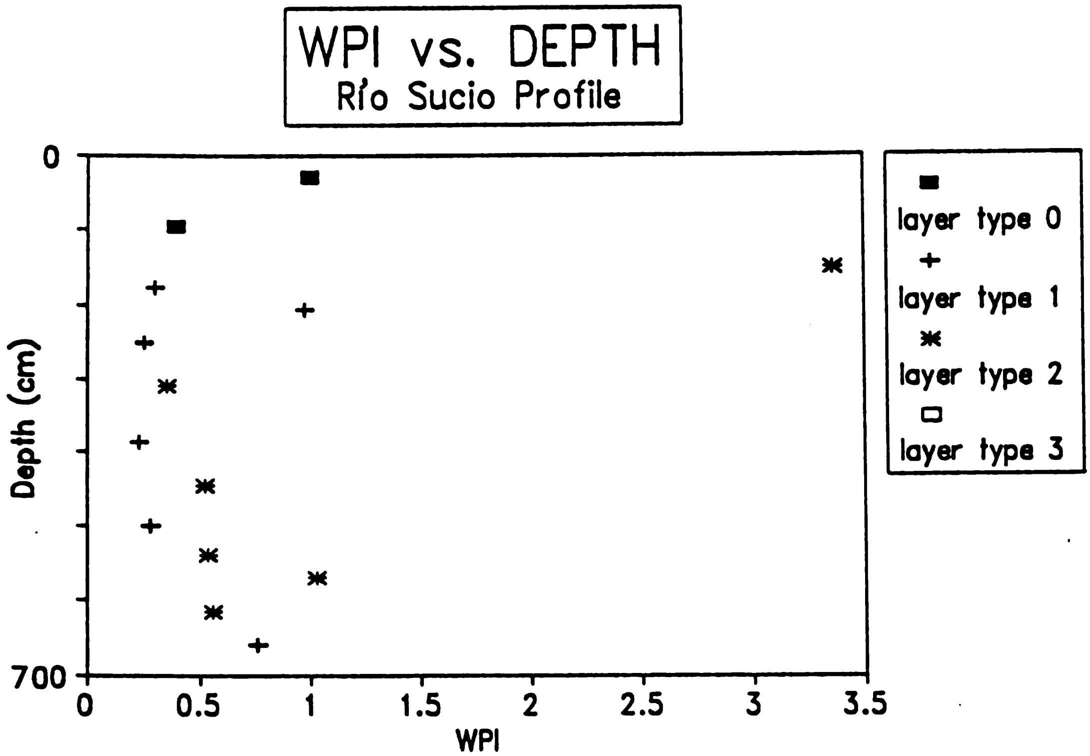

figure 5.7: WPI versus depth, Río Sucio Profile.

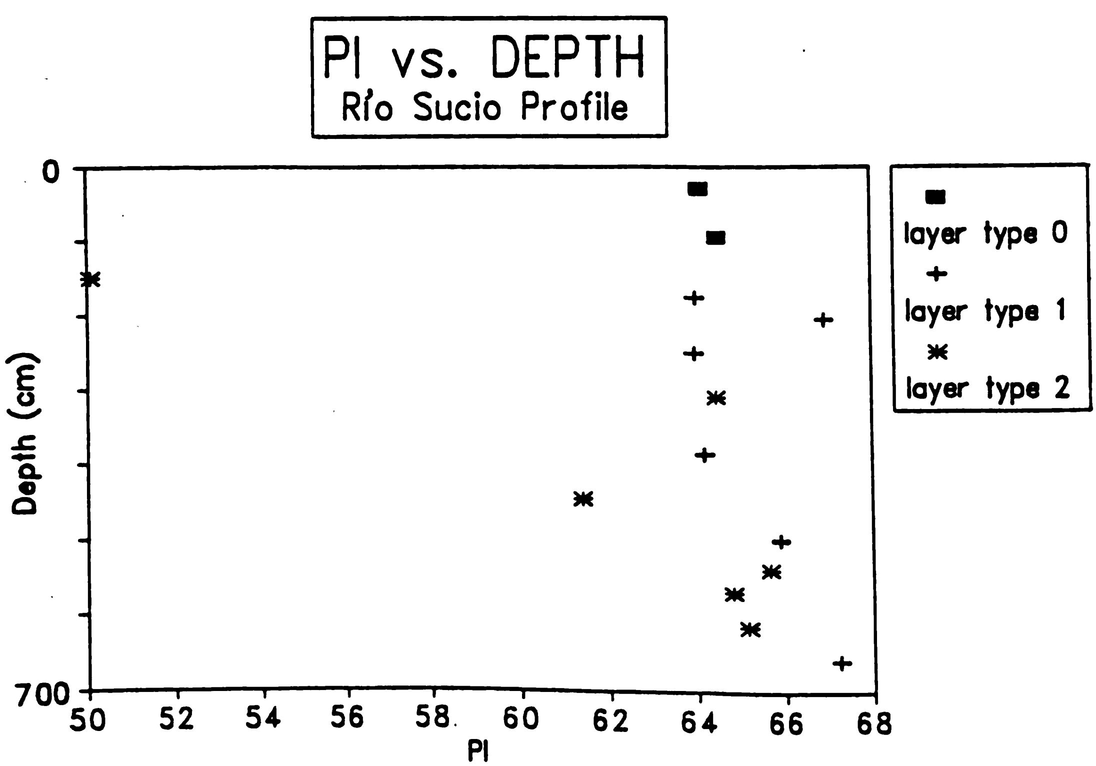

figure 5.8: PI versus depth, Río Sucio Profile.

5.2.4. Neguev Profile.

Sample	Depth cm	Layer-type	ΣR_2O_3	SiO_2	ΣBases	WPI	PI
A	30	0	50.2	48.6	0.7	0.7	49.2
B	85	2	78.6	19.9	0.5	0.5	20.2
C	145	2	44.9	50.5	3.6	3.6	53.0
D	190	2	46.4	51.3	1.6	1.6	52.5
E	235	1	34.9	64.4	0.3	0.3	64.9
F	315	4	32.0	66.2	1.4	1.4	67.4
G	375	2	30.6	67.3	1.8	1.8	68.8
H	425	4	30.6	66.9	2.2	2.2	68.6
I	490	2	32.2	65.8	1.5	1.5	67.1
J	535	1	34.4	64.2	0.8	0.8	65.1
K	570	2	30.4	59.6	9.2	9.2	66.2
L	610	2	22.3	55.0	21.4	21.7	71.2
M	635	3	31.3	58.2	9.5	9.6	65.0
N	655	2	34.3	63.3	1.8	1.8	64.9
Fresh sediment:		1				11.8	78.9
		2				18.1	81.1

Table 5.8.: **Analyse results of profile Río Sucio.**
ΣR_2O_3, SiO_2 and ΣBases in molair fraction %.
Fresh sediment data from van Seeters, 1992.

The samples consists for the major part of the oxides of the elements Al, Fe and Si. In the topsoil the ΣR_2O_3 content is about 50 % (Al_2O_3 = 37 %, Fe_2O_3 = 11 % and TiO_2 = 1%) and it decreases to about 30 % (Al_2O_3 = 21 %, Fe_2O_3 = 8 % and TiO_2 = 1 %) at greater depth, except for a high value just beneath the topsoil and a low value at 610 cm depth. SiO_2 content increases from about 48 % in the top soil to beween 55 and 68 % at greater depth, a very low value occurs just beneath the topsoil. Throughout the profile the base-ion content is very low, except for the content between 550 and 650 cm where it is higher than 9 %.

The WPI seems to increase slightly with depth from 0.7 in the top soil to about 1.8 at 655 cm depth, except for three very high values between 550 and 650 cm. The WPI of layer-type 2, 3 and 4 seem to be higher than that of layer-type 1 (see figure 5.9.).

The PI increases with depth from 49.0 in the top soil to about 68 at 425 cm depth, except for the low value for the layer-type 2 layer beneath the top soil. Beneath 425 cm it seems to decrease again to about 65 (see figure 5.10.).

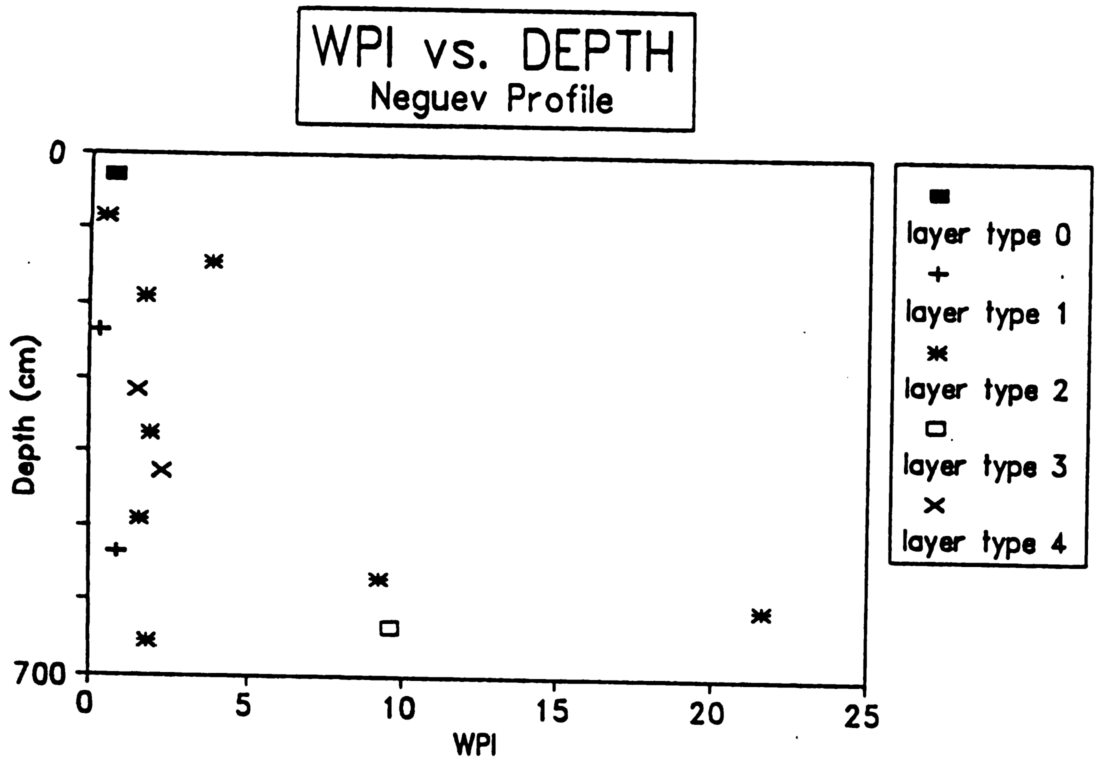

figure 5.9: WPI versus depth, Neguev Profile.

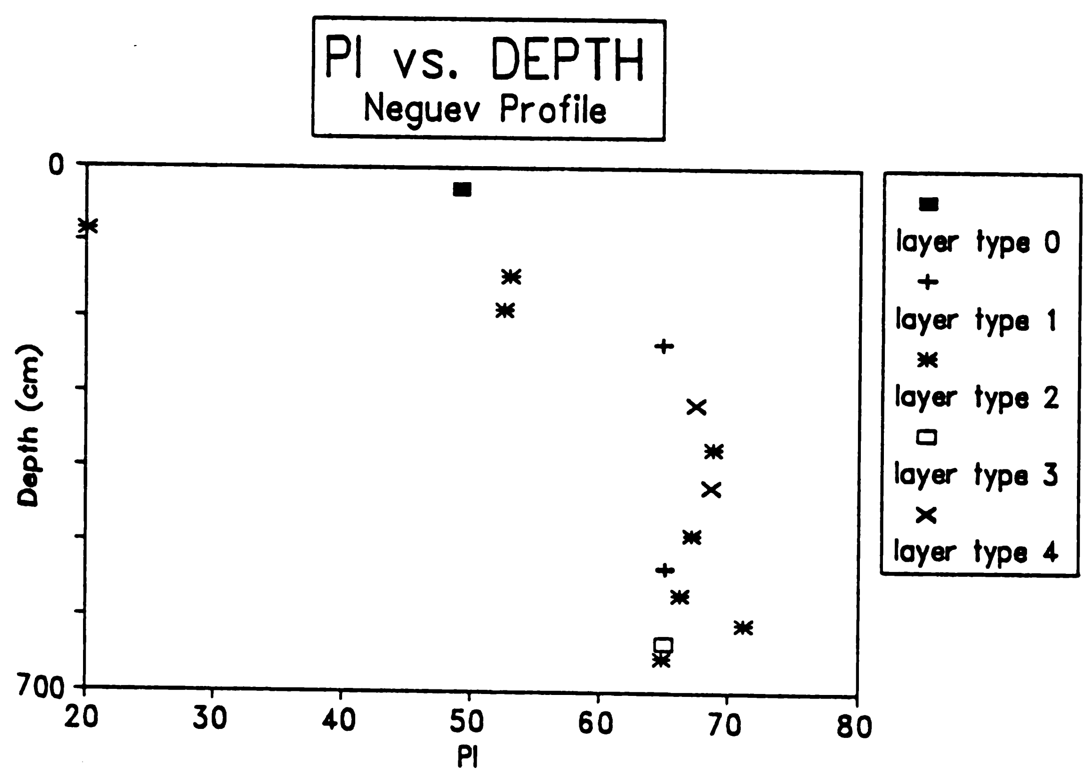

figure 5.10: PI versus depth, Neguev Profile.

6.Discussion

6.1.Influence of layer-depth.

The top soils of the four profiles are strongly weathered and homogenised. It is not possible to determine the parent material. Occurrence of organic matter will probably influence the weathering processes. Therefor the top soils will not be discussed.

The clay fractions of the layers underlying the topsoil, mainly consist of the following minerals: 1.0nm-halloysite, 0.7nm-halloysite or -kaolinite, gibbsite, some amorphous clay minerals and cristobalite. These minerals are supposed to be secondary since they are typically weathering products and they occur in large quantaties in the clay fraction. Gibbsite is stable at the relatively low H_4SiO_4-concentrations (figure 2.1), 0.7nm-halloysite or -kaolinite is likely to be a rekristallisation product of 1.0nm-halloysite. Cristobalite is stable at relatively high H_4SiO_4-concentrations.

In all profiles the clay-content, the gibbsite content and the amount of 0.7nm-halloysite or -kaolinite compared to 1.0nm-halloysite (figure 6.1), decrease with depth. Except for some samples of the Río Frío Dos Profile in which the Aratio is 0, this will be dicusses in chapter 6.4. The cristobalite-content seems to increase with depth. This indicates that leaching decreases with depth. In the layers just beneath the top soil the silica-concentration is probably lowest and gibbsite can be formed, in the lower part of the profile the silica-concentration is higher so cristobalite can precepitate. In the upper part of the profile more 0.7nm-clay minerals have formed, probably by recristallisation of 1.0nm-halloysite.

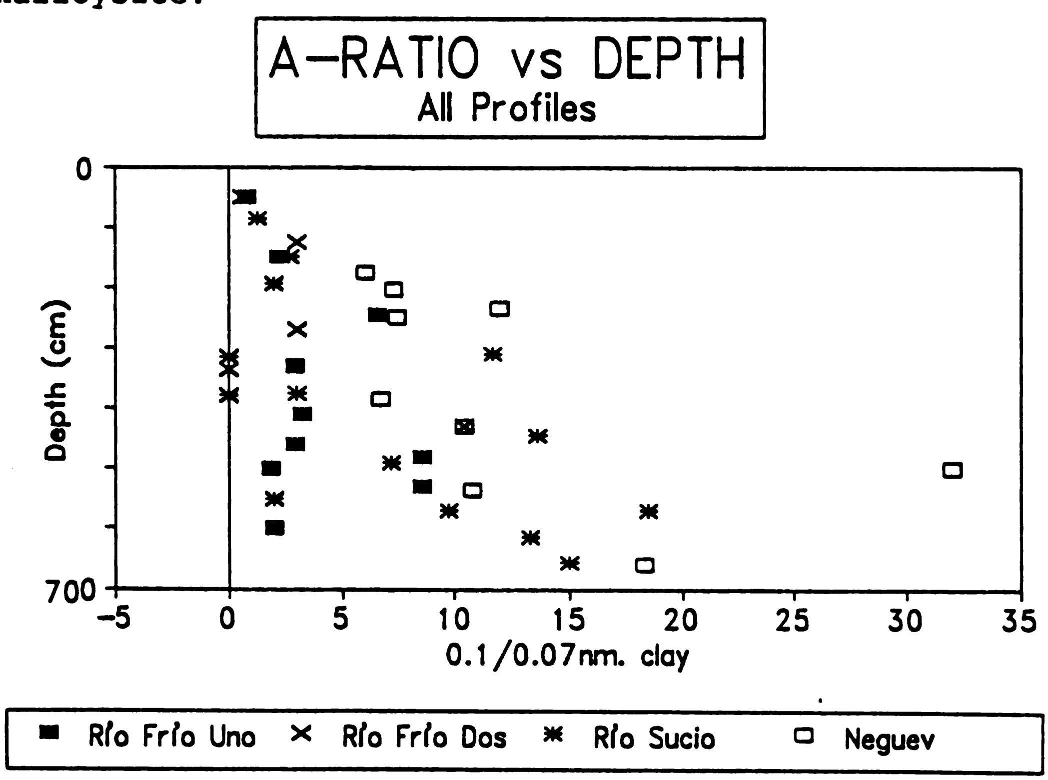

figure 6.1: Aratio versus depth.

The discussion of the chemical composition will be restricted to the Río Frío Uno and the Río Frío Dos Profile. The composition of the Río Sucio Profile is probably influenced by its low topographical situation and the composition of the sediments of the Negeuv Profile seems to be too heterogenous.

The WPI is a measure for the the base-ion content in the samples. During weathering of the primary minerals the base-ions are rapidly washed out, so the WPI can be seen as an indicater for the amount of unweathered base-ion containing primary material (probably mainly plagioclase, augite, hypersthene and some volcanic glass (Niewenhuyse et al, in prep.)). In all profiles the WPI increases with depth, which suggests that the amount of unweathered material in the upper part is lower than that in the lower part. The PI, which is a measure for the silica-content in the samples, also increases with depth. Silica leaching is probably most advanced in the upper part and decreases with depth.

It can be concluded that the weathering grade of the sediments decreases with depth. In the upper parts of the profiles less primary minerals are left and more silica is leached than in the lower parts.

Factors influencing the weathering rate are: Temperature, the amount of percolating water and the ionic activities in the soil solution. The temperature plays no important role since it probably is almost constant throughout the profiles. If only downward vertical water percolation is considered, the amount of percolating water is probably also nearly constant throughout the profile (annual rainfall is nearly 3000 mm, evapotranrpiration can be about 1000 mm a year).
An explanation for the difference in weathering stage with depth could be difference in ion-activities in the soil solution. During the downward percolation, the soil water can take up liberated ions. The higher concentration of solutes in the soil solution at greater depth could cause a lower weathering rate of the sediments at these depths. The concentration of protons can also influence the weathering rate. Just beneath the top soil it is probably higher due to a higher pCO_2, which can cause a higher weathering rate.

If the concentration of dissolved ions would indeed control the weathering rate of a sediment containing mainly feldspars and pyroxenes, it is probably a diffusion controlled proces. The diffusion of the dissolved ions from the mineral surface would be the rate controlling step. In layers with less water percolation the slower removal of solutes in the soil solution will cause higher ion-activities. This can result in a lower weathering rate of primary minerals in these layers.

If not only vertical water percolation is considered, the differences in weathering stage between the upper and the lower parts of the profiles can also be explained by the occurrence of lateral water movement. Removal of part of the percolating water by a lateral flow, will result in a higher amount of percolating water and a higher weathering rate in the upper parts than in the lower parts. This can be the case in the investigated profiles.

6.2. Influence of layer-type.

In this chapter the discussion will again be limited to the Río Frío Uno and the Río Frío Dos Profiles.

Differences in mineralogy and chemistry between the layer-types seem to exit.

Gibbsite only occurs in the coarse (type 2- and 3-) sediments, with a predominance in the coarsest (type 3-) layers. In the Río Frío Uno Profile the coarser textured layers also contain more cristobalite than the fine textured layers. According to the Aratio, the fine textured sediments in this profile seem to contain more kaolinite than 1.0nm-halloysite. This can be partly a result of determining the Aratio by measuring the peak-height instead of the the peak-suface. The clay minerals in the fine textured layers are probably more poorly cristallized (figure 6.2). High Al_{ox}-values only occur in type 2- and type 3-layers, which will be dicussed later.

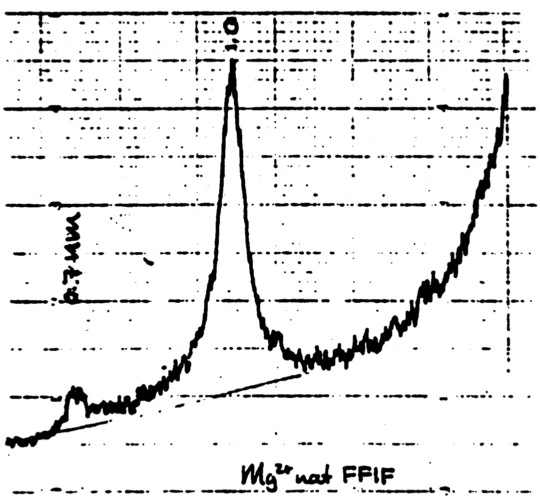

figure 6.2.a

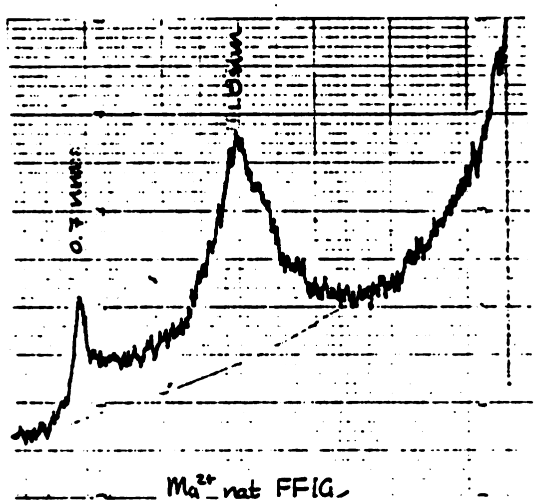

figure 6.2.b

figure 6.2: In coarse textured layer F1F (fig.b) the clay minerals are better cristallised than in the finer textured layer FIG (fig.a).

The WPI (a measure for the base-ion content) and the PI (measure for the silica content) are highest in the finest textured layers and lower in the coarsest textured layers (figure 6.3. and 6.4.). This indicates that fine textured sediments have suffered less base-ion and silica leaching and contain more primary minerals than the coarse textured ones.

It seems reasonable to conclude that weathering stage of the sediments is texture-dependent. When texture becomes coarser, weathering will be more advanced. This cannot be the result of differences in layer-depth since the layer-types occur throughout the whole profiles. Difference in chemical composition during sedimentation is probably also not the cause, since it would be expected that coarse textured fresh sediment contain more base-ions and silica than finer textured sediments. However the low WPI- and PI-value of the fine textured type 1-layer in the Río

Frío Dos Profile can be the result of a different (preweathered) chemical composition of the primary material.

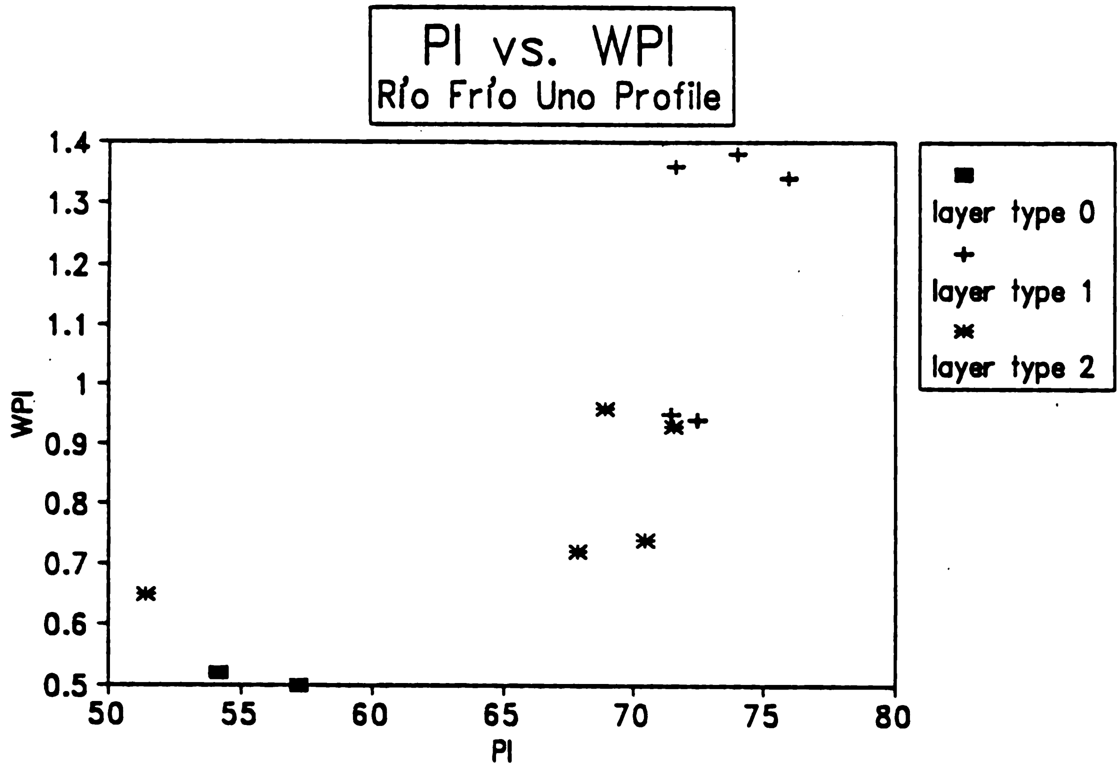

figure 6.3: PI versus WPI, Río Frío Uno Profile.

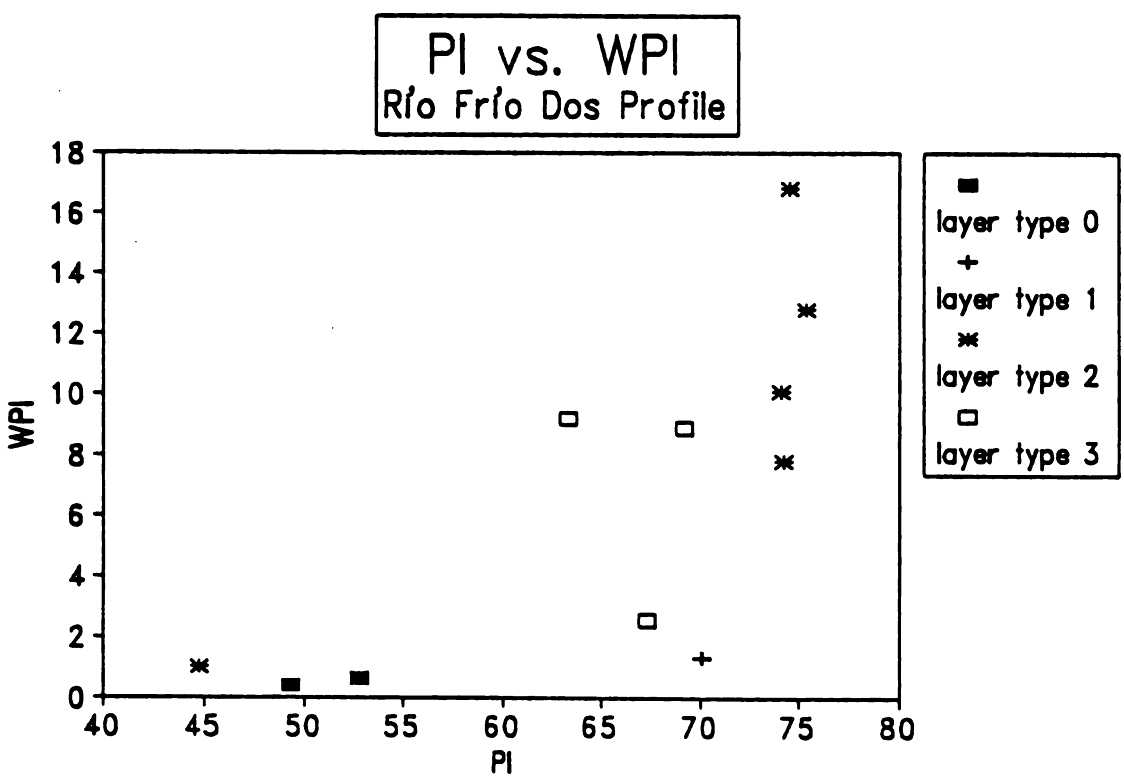

figure 6.4: PI versus WPI, Río Frío Dos Profile.

An explanation for the texture-depending weathering rate can be difference in permeability of the layer-types. Probaly most water will percolate through the coarse texured layers and weathering products will be removed more rapidly than in the finer textured layers. This will result in different ion-activities of the soil solutions. The highest will occur in the finest texuerd layers, the lowest in the coarsest textured layers. If weathering of the sediments is a diffusion controlled proces, the ionic strength of the soil solution will control the weathering rate. It will be highest in the coarsest textured and lowest in the finest textured layers.

This explanation only holds when there actualy can be lateral water flow. In both profiles the soil water can mainly follow the coarsest textured sediments. Evidence of stagnating water in the form of reduction mottles in the fine textured layers is found in the Río Frío Uno Profile.

The micro-hydrology in the profiles probably plays an important role in the weathering of the deposits.

The coarser textured sediments in the Río Frío Uno Profile also contain more cristobalite than the finer texured sediments. This is not expected since the coarse textured layers are stronger leached (occurrence gibbsite). The occurrence of critobalite in the coarse textured layers could be the result of seasonal variation. In the drier parts of the year the cirumstances for the forming of cristobalite could be more favourable (less water percolation, higher ion-activities), while in the more humid parts of the year the forming of gibbsite could be predominant.

6.3. Differences between the profiles.

Differences in mineralogy and chemistry between the profiles exist.

Variation in the amount of Al_{ox} in the profiles will be discussed later.

Generally the weathering of the deposites is characterised by rapid removal of the base-ions and a slower removal of silica. Part of the silica will precipitate in secondary products. The oxides of Fe, Al and Ti seem to be the least mobile components in the soil and undergo relative enrichment during weathering. The amount of base-ions between the profiles varies strongly.

The Río Frío Uno Profile, the Río Sucio Profile and the upper 550 cm of the Neguev Profile contain very little primary material comparing to fresh sediments (WPI profiles < 1.5, WPI fresh sediment ≈ 12-18). The Río Frío Dos Profile (beneath 200 cm) and the lower part of the Neguev contain relatively much primary material (WPI profiles ≈ 8-20). Deposits containing much primary minerals generally have a relatively high Si-content. This indicates that the Río Frío Dos Profile and the lower part of the Neguev Profile seem to be less weathered than the other deposits.

Maybe the Río Frío Dos Profile-deposits are younger, and therefor less weathered. However the top soil is not thinner than that of the Río Frío Uno Profile and both profiles seem to belong to the same formation (distance between them is several hundred meters), so differnce in age of the profiles is not likely to be the reason for a different weathering stage.

Another explanation can be differences in hydrology. The previus chapters pointed out that the micro-hydrology plays an important role in the weathering of the 'Red-hill'-deposits. In the Río Frío Uno and the Río Sucio Profile probably more water has percolated which can have resulted in a more advanced weathering. Field observations confirm appreciable difference in weathering stage within a few meters distance. The sample taken from the Río Frío Dos at 550cm depth, was almost fresh, while the same layer a few meters further seemed to be more weathered.

The differences in hydrology can be caused by the topographical situation of the deposits. In some situations lateral water transport in the upper part of the profile can be stimulated. This can result in differences in weathering stage throughout the profile.

The variety in chemical composition of the Neguev Profile-layers can have stemmed partly from differences in primary composition. The type 4-layer, likely to be a lahar, can have contained relatively much preweathered material. The underlying sands were probably relatively unweathered. The lahar, which is a relatively impermeable deposit, can also have prevented part of the soil water from percolating through the underlying sediments. So the the underlying sediments can be less weathered.

Beneath the top soil the Río Sucio Profile contains relatively little silica. This can be the result of its location on the bottom of a small valley. Probably more water has percolated through the profile which caused a stronger silica-leaching. Probably vertical water percolation was predominant so difference in weathering stage between the layer-types does not seem to exist.

6.4.Occurrence of allophane.

In order to determine the content of allophane-like products in the samples, the Al_{ox}-content was measured, which probably is a measure for the content of Al-humus complexes and allophane-like products. Since the organic matter-content in the layers beneath the top soil is supposed to be nil, the Al_{ox}-content is probably a measure allophane.
In the Río Frío Uno and the Río Sucio Profile allophane is almost absent. Some Río Frío Dos Profile-samples have allophane-contents of 6 %. In these samples the clay fraction is almost completely amorphous (figure 6.5.) and the Aratio is 0. Allophane content increases lineairly with the amount of primary material (figure 6.6.). The lower part of the Negeuv Profile shows the same correlation. However in the upper part some high allophane-contents occur in stronger weathered material.

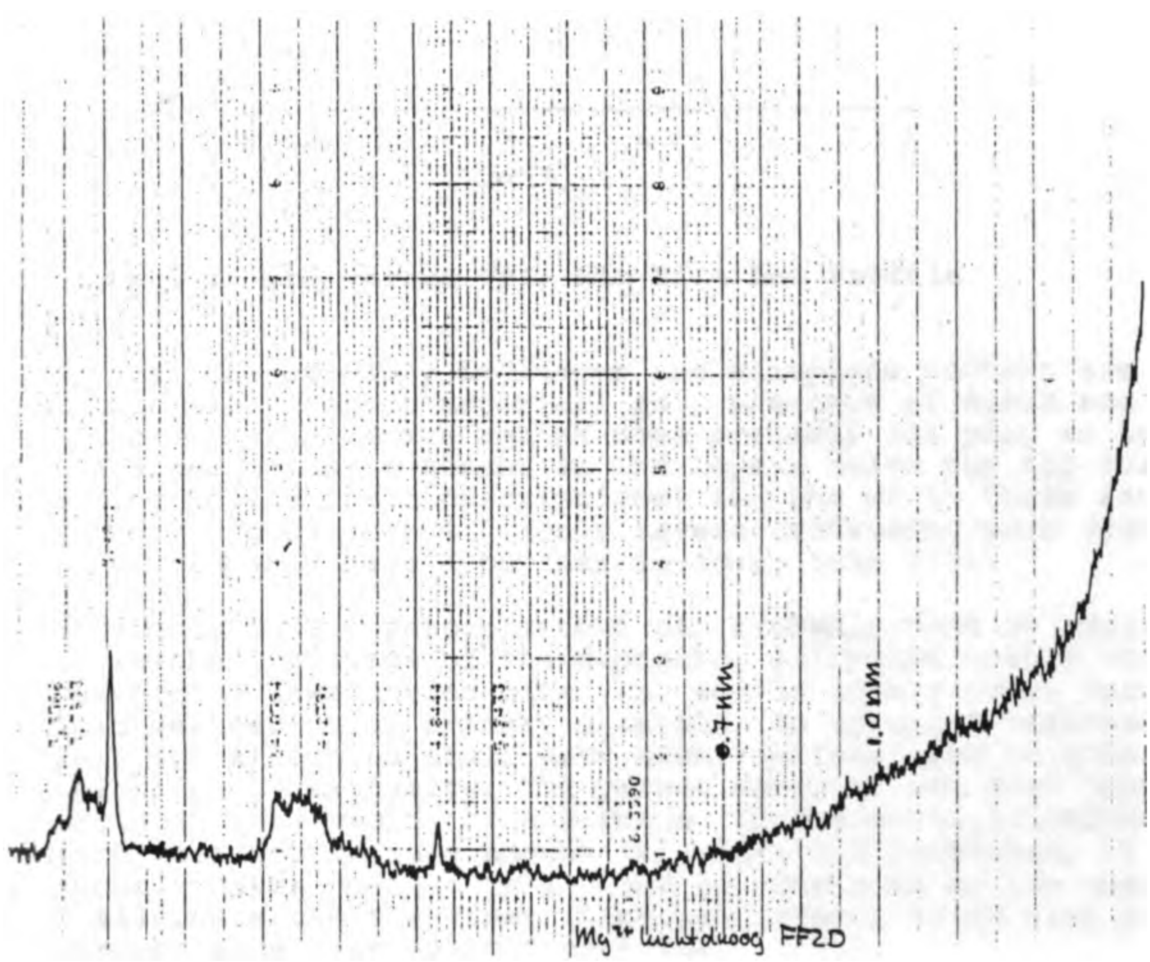

figure 6.5: Clay fraction is almost amorphous in diffractogram of sample F2D.

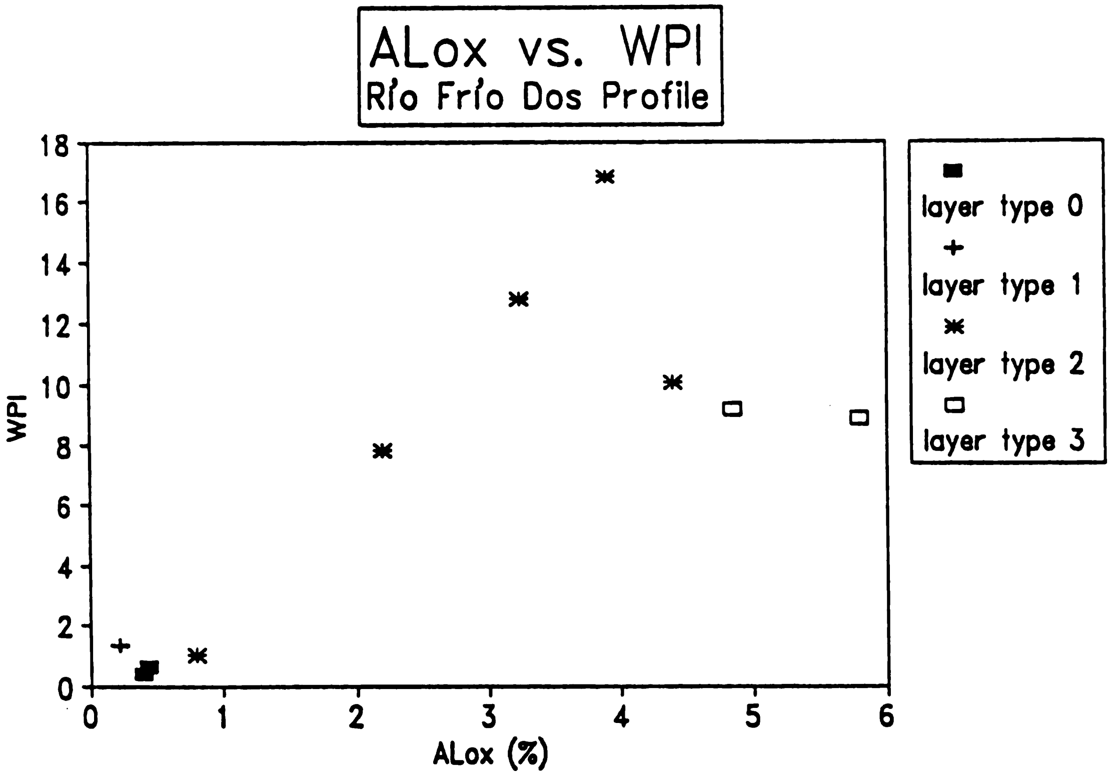

figure 6.6: Al_{ox} versus WPI, Río Frío Dos Profile.

Factors that probably influence the allophane content are (see chapter 2.1): Parent material, pH , presence of humus and the age of the deposits. Humus and pH does probably not play an important role since humus is absent in the layers below the top soil (according to the field descriptions) and the pH in these layers is probably higher than 4.7 (only layers containing much organic matter probably have a pH that is lower than 4.7).

Difference in allophane-content can probably best be explained by the weathering stage of the deposits. Allophane mostly occurs in presence of unweathered material, and is likely to be formed by rapid weathering of primary minerals. In stronger weathered material, the allophane could have been recrisallised to gibbsite, kaolinite or halloysite. The parent material can also have played a role in the forming of allophane, in preweathered sediments, which does not contain enough feldspars and pyroxenes, it is probably never formed. This could be confirmed by the absence of of allophane the the finest textured layers, which have probaly cotained some preweathered material.

The presence of allophane in the upper part of the Neguev Profile with the absence of primary minerals, could indicate that the formation of allophane has just stopped since the primary minerals are all dissolved.

7.Conclusions

The 'Redhill'-deposits in the Atlantic Zone of Costa Rica consist for the major part of fluvial sediments. As a result of the humid tropical conditions they are deeply weathered.

Weathering is characterised by rapid dissolution of the primary minerals. The liberated are base-ions are almost completely washed out (in some cases todepths of at least 600 cm). The silica will partly be washed out and will partly precipitate in secondary minerals. The oxides of Fe, Al and Ti are the least mobile components.

Most important secondary minerals are 1.0nm-halloysite, 0.7nm-halloysite or -kaolinite, gibbsite, cristobalite and some amorphous and poorly ordered clay minerals, for instance allophane.

Weathering seems to be most advanced in the upper part of the deposits and weathering intensity decreases with depth. This can be explained by difference in ionic strength of the soil solution between the upper and lower parts. Higher ion-activities probably slow down the weathering rate. Lateral water transport also seems to play an important role, since it causes differences in the amount of percolating water between the upper and the lower parts of the profiles. The deepest situated layers will receive less percolating water (probanly because of lateral removal) and are therefore less weathered.

Weathering rate of the sediments seems to be depend partly on texture. Weathering of coarse textured sediments is more advanced than that of fine textured sediments, which can be the result differences in permeability. Probably most water will percolate through the coarsest texured and therefor most permeable sediments. In the finer textured sediments the water probably stagnates. This causes differences ionic strenghts of the soil solutions. In the coarse textured sediments it will be lowest, which will result in a higher weathering rate of the coarse textured sediments. Weathering rate of the finer textured sediments will be lower.

Differences in weathering stage between the different locations exist. Some deposits contain more primary material and more early stage weathering products (for instance allophane). This can be the result of differences in (micro-) hydrology of the deposits.

Hydrology probably strongly influence the weathering processes. More research should be done in order to determine the (micro-) hydrology of the 'Redhill'-deposits and its influence on the weathering rate.

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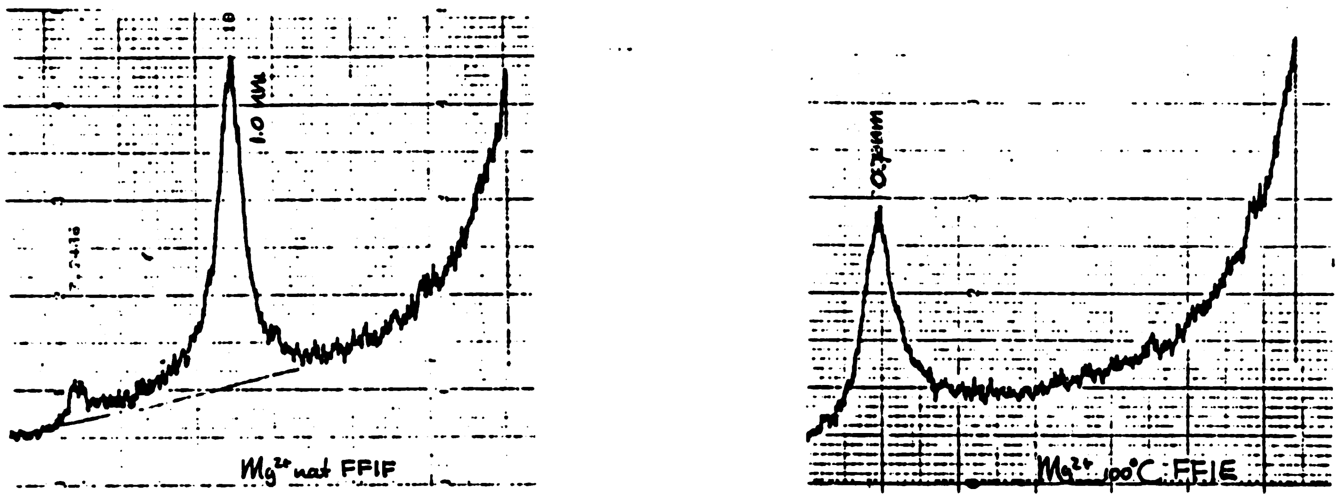
APPENDIX 1

Analysis data:

XRD:



Typical x-ray diffractograms. After heating at 100°C, the 1.0 nm peak is transformed into a 0.7 nm peak; 1.0 nm halloysite cristallizes into 0.7 nm-halloysite or kaolinite.

Texture analysis and XRD-results:

SAMPLE	TEXT1	TEXT2	TEXT3	TEXT4	TEXT5	TEXT6	FEOX2	ALOX	A10\A7	GIBBS	CRYST	GOETH	QUARTZ
F1A1	0.00	2.00	2.00	4.00	34.00	58.00	0.34	0.36	0.81	3	1	1	1
F1A2	0.00	1.00	2.00	4.00	36.00	57.00	0.43	0.42	2.22	3	1	1	1
F1B	2.00	12.00	8.00	8.00	43.00	27.00	0.49	0.43	6.50	3	2	0	0
F1C	0.00	0.00	1.00	12.00	49.00	38.00	0.13	0.3	2.88	0	1	0	0
F1D	1.00	17.00	13.00	7.00	53.00	9.00	0.38	0.4	3.20	2	2	0	0
F1E	0.00	0.00	2.00	12.00	53.00	33.00	0.11	0.29	2.91	0	1	1	0
F1F	0.00	12.00	26.00	8.00	48.00	6.00	0.07	0.4	8.50	1	3	0	0
F1G	0.00	0.00	0.00	1.00	54.00	45.00	0.06	0.4	1.85	0	1	1	0
F1H	0.00	13.00	8.00	10.00	58.00	11.00	0.28	0.34	8.50	0	3	1	1
F1I													
F1J	1.00	30.00	10.00	11.00	42.00	6.00	0.17	0.29					
F1K	0.00	0.00	0.00	6.00	58.00	36.00	0.19	0.45	2.00	0	1	1	0
F2A1	0.00	3.00	3.00	4.00	37.00	53.00	0.37	0.44	0.57	3	1	1	1
F2A2	1.00	2.00	2.00	4.00	35.00	56.00	0.72	0.4	3.00	3	0	1	0
F2B	12.00	12.00	8.00	14.00	32.00	22.00	0.51	0.8	2.00	3	2	1	0
F2C	55.00	15.00	7.00	8.00	12.00	3.00	0.48	4.85	3.00	1	3	0	0
F2D	33.00	39.00	12.00	4.00	7.00	5.00	0.38	4.4	0.00	0	0	0	0
F2E	43.00	29.00	11.00	4.00	8.00	5.00	0.37	5.8	0.00	1	1	0	0
F2F	36.00	44.00	8.00	2.00	7.00	3.00	0.32	3.25	0.00	0	0	0	0
F2G													
F2H	4.00	5.00	4.00	6.00	58.00	23.00	0.4	0.22	10.40	0	2	0	0
F2I	27.00	38.00	7.00	5.00	18.00	5.00	0.3	2.2		0	3	0	1
F2J	0.00	3.00	48.00	36.00	13.00	0.00	0.1	3.9	2.00	0	0	0	0
S3A	1.00	1.00	1.00	3.00	18.00	76.00	0.42	0.45	1.38	1	1	1	0
S3B	0.00	0.00	0.00	3.00	32.00	65.00	0.24	0.26	2.00	1	1	1	0
S3C	0.00	4.00	11.00	15.00	44.00	26.00	0.38	1.75	2.71	2	1	1	0
S3D	0.00	0.00	0.00	4.00	29.00	67.00	0.07	0.4	6.00	1	1	1	0
S3E	0.00	0.00	0.00	2.00	39.00	59.00	0.09	0.36	7.25	0	0	1	0
S3F	0.00	2.00	5.00	19.00	39.00	35.00	0.1	0.4	7.43	0	0	0	0
S3G	0.00	3.00	5.00	21.00	54.00	17.00	0.48	0.38	11.67	0	1	0	0
S3H	0.00	0.00	1.00	9.00	63.00	27.00	0.2	0.32	6.67	0	0	0	0
S3I	1.00	3.00	8.00	27.00	43.00	18.00	0.46	0.48	13.67	0	0	0	0
S3J	0.00	0.00	0.00	0.00	64.00	36.00	0.34	0.4	32.00	1	1	0	1
S3K	0.00	1.00	3.00	16.00	72.00	8.00	0.68	0.47					
S3L	0.00	0.00	13.00	26.00	52.00	9.00	0.9	0.52	18.50	0	2	0	0
S3M	0.00	1.00	7.00	21.00	67.00	4.00	0.47	0.45	13.33	0	2	0	1
S3N	0.00	0.00	0.00	0.00	87.00	13.00	0.3	0.24	18.33	0	1	0	0
N4A	0.00	1.00	2.00	10.00	38.00	49.00	0.66	0.44	1.00	3	0	1	2
N4B	1.00	2.00	15.00	43.00	21.00	18.00	1.25	2.15	1.25	2	0	1	1
N4C							1.1	19.7					
N4D							1.3	7.3					
N4E	0.00	0.00	2.00	14.00	64.00	20.00	0.48	0.45	12.00	0	1	0	0
N4F	5.00	10.00	9.00	21.00	45.00	10.00	0.32	0.27	6.33	0	2	0	0
N4G	0.00	0.00	2.00	14.00	64.00	20.00	0.25	0.5	3.00	0	1	1	0
N4H	0.00	2.00	5.00	20.00	61.00	12.00	0.3	0.26	4.14	0	3	0	1
N4I	0.00	1.00	6.00	17.00	62.00	14.00	0.5	0.23	7.17	0	3	0	1
N4J	0.00	0.00	0.00	1.00	50.00	49.00	2.6	0.5	10.75	0	1	0	0
N4K	0.00	3.00	10.00	26.00	51.00	10.00	0.51	0.94	9.75	0	2	0	0
N4L	0.00	15.00	29.00	21.00	27.00	8.00	0.23	4.6					
N4M	44.00	7.00	8.00	15.00	19.00	7.00	0.81	1.3	24.00	1	2	0	1
N4N	0.00	1.00	3.00	29.00	57.00	10.00	0.56	0.45	15.00	0	2	0	1

text1= >2mm, text2= 2mm-500µm, text3= 500-212µm, text4= 212-53µm, text5= silt, text6= clay.

A10/A7= Aratio
gibbs= gibbsite, cryst= cristobalite, goeth= goethite, 3= much, 2= intermediate, 1= little, 0= nil.

XRF-results of the major elements (weight %):

SAMPLE	SiO2%	TiO2%	Al2O3%	Fe2O3%	MnO%	MgO%	CaO%	Na2O%	K2O%	P2O5%	BaO%	L.I.%	SUM%
F1A1	31.42	2.26	35.29	13.96	0.05	0.10	0.01	0.04	0.12	0.21	0.03	18.26	101.39
F1A2	27.99	2.38	35.63	13.93	0.05	0.13	0.01	0.04	0.04	0.18	0.03	18.17	98.25
F1B	25.65	2.94	37.52	12.45	0.15	0.17	0.01	0.04	0.04	0.41	0.03	19.05	98.15
F1C	47.71	1.77	30.53	8.81	0.02	0.35	0.01	0.04	0.11	0.19	0.03	12.25	101.49
F1D	42.67	1.93	30.46	11.76	0.07	0.22	0.01	0.04	0.12	0.35	0.03	13.44	100.83
F1E	49.09	1.77	30.76	7.43	0.02	0.34	0.01	0.04	0.13	0.20	0.03	11.99	101.47
F1F	44.79	1.71	30.78	7.71	0.03	0.23	0.01	0.04	0.13	0.20	0.03	12.86	98.22
F1G	49.33	1.79	29.03	6.19	0.02	0.47	0.01	0.04	0.29	0.24	0.03	11.79	98.95
F1H	43.19	2.43	27.79	13.05	0.07	0.33	0.01	0.04	0.10	0.37	0.04	12.08	99.22
F1I	51.46	1.64	27.23	5.92	0.02	0.45	0.01	0.04	0.31	0.22	0.03	11.33	98.40
F1J	45.81	1.75	28.65	9.02	0.07	0.32	0.01	0.04	0.12	0.21	0.03	12.32	98.06
F1K	46.84	1.57	28.79	9.85	0.02	0.49	0.01	0.04	0.19	0.28	0.03	12.22	100.02
F2A1	26.34	2.35	34.98	14.39	0.12	0.12	0.01	0.04	0.13	0.26	0.03	19.69	98.13
F2A2	24.77	2.53	37.45	16.16	0.08	0.08	0.01	0.04	0.05	0.20	0.03	19.36	100.40
F2B	20.72	2.72	37.27	16.48	0.08	0.26	0.01	0.04	0.05	0.47	0.03	20.29	98.10
F2C	36.35	2.87	27.51	17.40	0.14	2.92	0.40	0.30	1.13	0.65	0.03	11.96	101.60
F2D	46.47	1.79	23.44	10.75	0.10	2.61	1.01	0.81	2.02	0.47	0.03	9.13	98.62
F2E	41.42	1.82	27.59	11.01	0.40	2.47	0.56	0.50	1.69	0.60	0.05	12.48	100.59
F2F	47.53	1.56	23.30	9.28	0.12	3.31	1.77	0.86	2.51	0.42	0.06	8.79	99.52
F2G	39.58	1.63	29.52	10.59	2.11	0.70	0.07	0.04	0.61	0.22	0.26	13.30	98.60
F2H	44.41	2.11	27.47	12.36	0.22	0.47	0.03	0.04	0.14	0.18	0.11	11.64	98.97
F2I	48.73	1.52	26.96	8.10	0.17	2.01	0.93	0.49	1.70	0.40	0.14	10.47	101.62
F2J	46.12	1.43	24.03	8.94	0.13	4.84	3.50	0.62	1.48	0.32	0.08	9.28	100.76
S3A	37.42	1.95	30.12	14.33	0.11	0.33	0.01	0.04	0.08	0.38	0.03	14.50	99.01
S3B	38.53	1.98	33.92	9.94	0.06	0.12	0.01	0.04	0.02	0.28	0.03	14.78	99.41
S3C	25.05	3.57	31.67	21.70	0.10	1.06	0.10	0.04	0.02	0.61	0.03	15.00	98.68
S3D	38.27	1.83	33.39	11.57	0.03	0.09	0.01	0.04	0.00	0.14	0.03	14.16	99.17
S3E	40.78	1.67	30.53	11.75	0.05	0.37	0.01	0.04	0.00	0.16	0.03	13.04	98.09
S3F	38.35	2.12	32.34	12.98	0.04	0.07	0.01	0.04	0.00	0.17	0.03	13.52	99.28
S3G	38.51	2.07	31.43	13.25	0.06	0.11	0.01	0.04	0.00	0.32	0.03	13.28	98.75
S3H	38.70	2.00	33.26	11.83	0.05	0.06	0.01	0.04	0.00	0.23	0.07	13.52	99.40
S3I	35.40	2.05	34.27	12.18	0.07	0.17	0.01	0.04	0.00	0.56	0.03	14.37	98.87
S3J	39.90	1.74	33.41	9.23	0.04	0.05	0.05	0.04	0.00	0.28	0.07	13.73	98.23
S3K	39.96	1.81	32.55	11.02	0.08	0.15	0.06	0.04	0.00	0.42	0.05	13.27	99.11
S3L	38.61	1.95	28.27	16.79	0.08	0.31	0.11	0.04	0.00	0.47	0.03	12.43	98.75
S3M	39.11	1.92	31.63	12.26	0.27	0.17	0.04	0.04	0.00	0.24	0.10	13.12	98.59
S3N	42.02	1.69	33.01	9.34	0.09	0.18	0.10	0.04	0.10	0.04	0.17	13.13	100.08
N4A	24.21	2.31	37.39	15.20	0.10	0.18	0.01	0.04	0.06	0.33	0.03	19.36	98.84
N4B	7.64	2.39	46.57	16.68	0.11	0.09	0.01	0.04	0.00	0.73	0.03	24.20	98.04
N4C	18.34	1.26	25.15	8.94	0.09	0.85	0.05	0.04	0.00	0.44	0.03	45.51	100.40
N4D	27.49	2.00	38.12	13.95	0.14	0.55	0.01	0.04	0.00	0.59	0.06	17.78	100.36
N4E	38.79	1.56	31.79	12.49	0.12	0.10	0.01	0.04	0.00	0.13	0.18	13.29	98.10
N4F	41.99	1.77	30.74	11.83	0.17	0.56	0.01	0.04	0.00	0.24	0.12	12.34	99.43
N4G	42.84	1.77	29.24	11.57	0.14	0.74	0.01	0.04	0.00	0.14	0.03	12.24	98.38
N4H	42.74	1.96	28.76	12.37	0.13	0.91	0.01	0.04	0.00	0.18	0.03	11.83	98.56
N4I	41.24	1.82	30.34	12.02	0.17	0.60	0.01	0.04	0.00	0.22	0.07	12.43	98.60
N4J	39.12	1.88	31.88	11.95	0.25	0.30	0.01	0.04	0.00	0.33	0.10	13.40	98.90
N4K	39.59	2.03	28.25	14.66	0.19	2.83	1.72	0.04	0.00	0.66	0.16	11.40	101.29
N4L	40.91	1.80	22.74	12.60	0.19	6.34	5.23	0.44	0.67	1.72	0.08	8.81	101.52
N4M	37.18	2.06	27.59	14.98	0.14	3.38	0.94	0.04	0.00	0.96	0.23	11.50	98.83
N4N	38.52	1.95	30.42	13.67	0.17	0.69	0.01	0.04	0.00	0.37	0.19	12.64	98.27

XRF-results of the major elements (molair %):

SAMPLE	SIO2MOL%	TIO2MOL%	AL2O3ML%	FE2O3ML%	MNOMOL%	MGOMOL%	CAOMOL%	NA2OMOL%	K2OMOL%	P2O5MOL%	BAOMOL%
F1A1	56.77	1.04	31.94	9.50	0.08	0.27	0.02	0.07	0.14	0.16	0.02
F1A2	53.74	1.16	34.26	10.07	0.06	0.37	0.02	0.07	0.05	0.15	0.02
F1B	50.77	1.48	37.20	9.28	0.25	0.50	0.02	0.08	0.05	0.34	0.02
F1C	70.66	0.67	22.65	4.91	0.03	0.77	0.02	0.06	0.10	0.12	0.02
F1D	67.18	0.77	24.02	6.97	0.09	0.52	0.02	0.06	0.12	0.23	0.02
F1E	71.67	0.66	22.49	4.08	0.02	0.74	0.02	0.06	0.12	0.12	0.02
F1F	69.83	0.68	24.03	4.53	0.04	0.53	0.02	0.06	0.13	0.13	0.02
F1G	72.84	0.67	21.47	3.44	0.03	1.04	0.02	0.06	0.27	0.15	0.02
F1H	68.04	0.97	21.93	7.74	0.09	0.78	0.02	0.06	0.10	0.25	0.02
F1I	74.81	0.61	19.83	3.24	0.02	0.98	0.02	0.06	0.29	0.14	0.02
F1J	70.73	0.69	22.16	5.24	0.09	0.74	0.02	0.06	0.12	0.14	0.02
F1K	70.53	0.60	21.71	5.58	0.03	1.10	0.02	0.06	0.18	0.18	0.02
F2A1	52.25	1.19	34.75	10.75	0.20	0.36	0.02	0.08	0.16	0.22	0.02
F2A2	48.93	1.27	37.05	12.02	0.13	0.24	0.02	0.08	0.06	0.17	0.02
F2B	44.06	1.47	39.69	13.20	0.14	0.82	0.02	0.08	0.07	0.42	0.03
F2C	57.14	1.15	21.66	10.30	0.19	6.85	0.67	0.46	1.13	0.43	0.02
F2D	66.33	0.65	16.76	5.78	0.12	5.56	1.54	1.12	1.84	0.28	0.02
F2E	62.47	0.70	20.84	6.25	0.51	5.56	0.90	0.73	1.63	0.38	0.03
F2F	65.41	0.55	16.06	4.81	0.14	6.79	2.61	1.15	2.20	0.24	0.03
F2G	63.53	0.67	23.73	6.40	2.87	1.68	0.12	0.06	0.62	0.15	0.16
F2H	68.83	0.83	21.32	7.21	0.29	1.09	0.05	0.06	0.14	0.12	0.07
F2I	68.07	0.54	18.86	4.26	0.20	4.19	1.39	0.66	1.52	0.24	0.08
F2J	61.76	0.49	16.12	4.51	0.15	9.67	5.02	0.80	1.26	0.18	0.04
S3A	63.15	0.84	25.46	9.11	0.16	0.83	0.02	0.07	0.09	0.27	0.02
S3B	64.02	0.84	28.23	6.22	0.08	0.30	0.02	0.06	0.02	0.20	0.02
S3C	48.09	1.74	30.45	15.69	0.16	3.04	0.21	0.07	0.02	0.50	0.02
S3D	63.68	0.77	27.83	7.25	0.04	0.22	0.02	0.06	0.00	0.10	0.02
S3E	66.16	0.69	24.80	7.18	0.07	0.90	0.02	0.06	0.00	0.11	0.02
S3F	63.66	0.89	26.89	8.11	0.06	0.17	0.02	0.06	0.00	0.12	0.02
S3G	63.99	0.87	26.16	8.29	0.08	0.27	0.02	0.06	0.00	0.23	0.02
S3H	63.83	0.84	27.48	7.35	0.07	0.15	0.02	0.06	0.00	0.16	0.05
S3I	60.74	0.89	29.45	7.87	0.10	0.43	0.02	0.07	0.00	0.41	0.02
S3J	65.52	0.73	27.48	5.71	0.06	0.12	0.09	0.06	0.00	0.19	0.05
S3K	65.01	0.75	26.52	6.75	0.11	0.36	0.10	0.06	0.00	0.29	0.03
S3L	63.83	0.82	23.41	10.45	0.11	0.76	0.19	0.06	0.00	0.33	0.02
S3M	64.37	0.80	26.07	7.60	0.38	0.42	0.07	0.06	0.00	0.17	0.06
S3N	66.55	0.68	26.19	5.57	0.12	0.43	0.17	0.06	0.10	0.03	0.11
N4A	48.58	1.18	37.57	11.48	0.17	0.54	0.02	0.08	0.08	0.28	0.02
N4B	19.87	1.58	60.66	16.34	0.24	0.35	0.03	0.10	0.00	0.80	0.03
N4C	50.58	0.88	34.74	9.29	0.21	3.50	0.15	0.11	0.00	0.51	0.03
N4D	51.28	0.95	35.62	9.80	0.22	1.53	0.02	0.07	0.00	0.47	0.04
N4E	64.40	0.66	26.43	7.81	0.17	0.25	0.02	0.06	0.00	0.09	0.12
N4F	66.16	0.71	24.26	7.02	0.23	1.32	0.02	0.06	0.00	0.16	0.07
N4G	67.32	0.71	23.01	6.85	0.19	1.73	0.02	0.06	0.00	0.09	0.02
N4H	66.88	0.78	22.54	7.29	0.17	2.12	0.02	0.06	0.00	0.12	0.02
N4I	65.84	0.74	24.26	7.23	0.23	1.43	0.02	0.06	0.00	0.15	0.04
N4J	64.18	0.78	26.20	7.38	0.35	0.73	0.02	0.06	0.00	0.23	0.06
N4K	59.64	0.78	21.31	8.32	0.24	6.36	2.78	0.06	0.00	0.42	0.09
N4L	55.04	0.62	15.32	6.38	0.22	12.72	7.54	0.57	0.58	0.98	0.04
N4M	58.22	0.82	21.64	8.83	0.19	7.89	1.58	0.06	0.00	0.64	0.14
N4N	63.30	0.81	25.04	8.46	0.24	1.69	0.02	0.06	0.00	0.26	0.12

XRF-results of the trace-elements (ppm):
results did not show important patterns.

Coppm	Crppm	Cuppm	Gappm	Lappm	Nbppm	Nippm	Pbppm	Rbppm	Srppm	Vppm	Znppm	Zrppm	Bappm
20.00	135.00	141.00	29.00	45.00	12.00	43.00	24.00	12.00	68.00	489.00	74.00	320.00	158.00
20.00	130.00	157.00	34.00	56.00	13.00	42.00	25.00	10.00	76.00	498.00	77.00	339.00	398.00
25.00	235.00	175.00	35.00	91.00	14.00	98.00	20.00	10.00	72.00	592.00	96.00	451.00	821.00
20.00	120.00	105.00	27.00	107.00	18.00	36.00	16.00	10.00	252.00	297.00	24.00	336.00	388.00
20.00	102.00	191.00	25.00	107.00	22.00	55.00	24.00	10.00	230.00	347.00	47.00	399.00	588.00
20.00	129.00	90.00	30.00	94.00	19.00	46.00	26.00	10.00	291.00	291.00	17.00	334.00	320.00
20.00	108.00	134.00	29.00	94.00	21.00	66.00	18.00	10.00	210.00	278.00	44.00	347.00	574.00
20.00	116.00	63.00	31.00	96.00	25.00	20.00	30.00	10.00	393.00	282.00	15.00	348.00	363.00
22.00	156.00	192.00	29.00	115.00	25.00	90.00	32.00	10.00	256.00	469.00	82.00	477.00	665.00
49.00	104.00	63.00	26.00	80.00	25.00	17.00	24.00	11.00	402.00	249.00	10.00	318.00	314.00
20.00	85.00	161.00	28.00	65.00	23.00	57.00	18.00	10.00	217.00	287.00	46.00	392.00	493.00
20.00	117.00	112.00	24.00	77.00	20.00	26.00	26.00	10.00	301.00	295.00	12.00	297.00	293.00
20.00	135.00	155.00	32.00	38.00	13.00	31.00	26.00	10.00	85.00	494.00	66.00	324.00	177.00
20.00	144.00	165.00	35.00	44.00	17.00	35.00	27.00	12.00	68.00	589.00	59.00	349.00	395.00
20.00	219.00	78.00	34.00	66.00	20.00	35.00	20.00	10.00	58.00	605.00	69.00	483.00	111.00
36.00	400.00	93.00	24.00	62.00	20.00	112.00	15.00	32.00	94.00	601.00	176.00	336.00	223.00
32.00	122.00	71.00	22.00	54.00	21.00	65.00	19.00	49.00	206.00	312.00	164.00	333.00	477.00
66.00	132.00	97.00	25.00	128.00	20.00	66.00	20.00	27.00	251.00	321.00	187.00	357.00	655.00
25.00	114.00	85.00	23.00	60.00	18.00	48.00	16.00	63.00	213.00	257.00	88.00	330.00	675.00
114.00	95.00	88.00	30.00	152.00	30.00	48.00	21.00	10.00	124.00	312.00	77.00	340.00	2319.00
20.00	139.00	95.00	26.00	247.00	33.00	60.00	24.00	10.00	150.00	398.00	44.00	408.00	1275.00
20.00	88.00	74.00	23.00	120.00	22.00	33.00	20.00	41.00	260.00	241.00	64.00	323.00	1206.00
20.00	134.00	54.00	22.00	59.00	22.00	37.00	14.00	23.00	240.00	240.00	74.00	305.00	800.00
20.00	184.00	151.00	29.00	74.00	15.00	73.00	23.00	10.00	173.00	396.00	46.00	330.00	577.00
20.00	179.00	162.00	34.00	100.00	17.00	95.00	22.00	10.00	153.00	365.00	39.00	341.00	629.00
47.00	400.00	147.00	31.00	190.00	13.00	130.00	20.00	10.00	81.00	942.00	123.00	344.00	533.00
20.00	142.00	122.00	28.00	68.00	13.00	129.00	21.00	10.00	86.00	336.00	35.00	290.00	489.00
20.00	91.00	102.00	28.00	117.00	16.00	42.00	15.00	10.00	179.00	298.00	19.00	276.00	539.00
20.00	141.00	190.00	32.00	105.00	14.00	67.00	16.00	10.00	118.00	398.00	40.00	284.00	530.00
21.00	113.00	167.00	29.00	118.00	16.00	57.00	10.00	10.00	106.00	389.00	69.00	271.00	679.00
29.00	132.00	205.00	31.00	92.00	13.00	70.00	11.00	10.00	91.00	367.00	75.00	278.00	941.00
87.00	124.00	155.00	32.00	75.00	16.00	54.00	12.00	10.00	64.00	375.00	145.00	275.00	655.00
20.00	112.00	236.00	29.00	120.00	19.00	43.00	11.00	10.00	132.00	302.00	83.00	292.00	837.00
24.00	102.00	160.00	29.00	64.00	16.00	37.00	10.00	10.00	69.00	322.00	128.00	234.00	717.00
37.00	122.00	121.00	26.00	55.00	24.00	42.00	13.00	10.00	31.00	406.00	130.00	232.00	575.00
41.00	98.00	128.00	27.00	55.00	18.00	30.00	10.00	10.00	42.00	348.00	179.00	260.00	1160.00
20.00	93.00	334.00	30.00	178.00	30.00	47.00	11.00	10.00	379.00	269.00	86.00	281.00	1668.00
20.00	223.00	97.00	36.00	35.00	12.00	53.00	20.00	11.00	35.00	509.00	104.00	278.00	187.00
24.00	207.00	84.00	38.00	29.00	10.00	25.00	14.00	10.00	23.00	564.00	57.00	288.00	50.00
20.00	87.00	90.00	22.00	40.00	16.00	23.00	10.00	10.00	10.00	255.00	43.00	159.00	50.00
38.00	138.00	388.00	30.00	78.00	21.00	253.00	11.00	10.00	14.00	387.00	146.00	256.00	887.00
20.00	82.00	129.00	28.00	123.00	19.00	41.00	10.00	10.00	39.00	265.00	173.00	205.00	1771.00
55.00	105.00	88.00	28.00	98.00	17.00	42.00	11.00	13.00	30.00	328.00	78.00	244.00	1303.00
20.00	101.00	89.00	26.00	104.00	25.00	32.00	12.00	10.00	82.00	301.00	40.00	258.00	527.00
21.00	136.00	102.00	25.00	67.00	15.00	50.00	14.00	10.00	48.00	381.00	70.00	281.00	609.00
20.00	112.00	134.00	28.00	77.00	13.00	51.00	12.00	10.00	86.00	334.00	63.00	254.00	986.00
39.00	116.00	114.00	29.00	48.00	11.00	48.00	13.00	10.00	44.00	354.00	20.00	266.00	1211.00
41.00	214.00	132.00	25.00	87.00	14.00	93.00	11.00	10.00	68.00	406.00	164.00	270.00	1660.00
36.00	241.00	149.00	22.00	66.00	13.00	75.00	10.00	10.00	150.00	329.00	132.00	233.00	833.00
43.00	315.00	155.00	25.00	107.00	17.00	115.00	22.00	15.00	131.00	408.00	177.00	285.00	2268.00
28.00	151.00	139.00	28.00	94.00	17.00	76.00	13.00	10.00	82.00	356.00	98.00	277.00	1954.00

APPEDIX 2

Field descriptions:

hfile description FF1.

te/season	: 10/7/91, middle of the rainy season
ner	: Frank van Ruitenbeek
cation	: Rio Puerto Viejo
rdinates	: 265000/540000, Rio Sucio
pe	: road cut, 6m deep
vation	: 60m
ndform	
ysiographic position	: top of hill
pography	: hilly
ope	: flat
getation	: bush and grassland
imate	: humic tropics
ology	: pleistocene alluvial deposits
ainage class	: well drained
isture conditions of soil	: moist
pth groundwater table	: > 6m
ck outcrops	: nil
rface stoniness	: nil
dence of erosion	: nil
sence of salts/alkali	: nil
man influence	: deforestation

aracteristics: The profile is situatdd in a 6m deep road cut en s built up of fluvial sand-rich and clay-rich layers with red, llow and brown clours.

rizons:

a 0-200: Dark yellish brown (10YR 3/6); clay; friable; weak arse angular blocky structure; diffuse and smooth boundary to:

b 200-290: Dark yellish brown (10YR 3/6);sandy clay loam; firm; oken, thin sesquioxides coatings; very few, strongly weathered, unded gravel; gradual and smooth boundary to:

c) 290-375: Yellowish red (5YR 4/6); clay; firm; very few small, oft, white concrations; in the upper 4cm frequent, large, hard, lack concrations; structureless; abrupt and smooth boundary to:

d 375-445: Strong brown (7.5YR 4/6); sandy clay; very friable; ew white, black and yellow, small and large (<3cm), soft nodules (concrations/mineral fragments?); structureless; abrupt and mooth boundary to:

e) 445-470: Yellowish brown (10YR 5/6); common medium, orange and lack mottles (<4cm); clay; firm; abrupt and wavy (containing ew, small, grey mottles) to:

f) 470-490: Dark yellowish brown (10YR 4/5); few, small, white ottles; coarse sandy loam; continuous, thick, sesquioxides along he layers; weakly cemented; strongly wearhered sand grains; ross lamination; abrupt and smooth boundary to:

g) 490-510: Yellowish brown (10YR 5/6) and strongly brown (7.5YR 5/8); few white and grey mottles; clay; firm; abrupt and wavy to:

h) 510-545: Dark yellowish brown (10YR 4/4); coarse sandy loam; continuous, thick, sesquioxides along the layers; weakly cemented; strongly weathered sand grains; few, rounded, weathered ravel; cross lamination; abrupt and smooth boundary to:

i) 545-560: Yellowish brown (10YR 5/6) and strongly brown (7.5YR 5/8); few fine/medium, distinct (reduction-) mottles; clay; firm; abrupt and smooth boundary to:

j) 560-595: Dark yellewish brown (10YR 4/4); coarse sandy loam; continuous, thin sesquioxides; weakly cemented; 575cm: discontiuous, piselitic, black/brown pan (<3cm); cross lamination; abrupt and smooth to:

k) 595-610: Yellowish brown (10YR 5/6) and strongly brown (7.5YR 5/8); common fine/medium,irregular grey (reduction-) mottles; many, medium, prominent, black mottles (<2mm); clay; firm;

DEPOSITS

Profile FF1:

a) 0-200: Soil

b) 200-290: Poorly sorted; sand with few pebbles; fluvial

c) 290-375: Clay; fluvial;

d) 375-445: Moderately sorted; sand with few pebbles (<3cm); fluvial

e) 445-470: Clay; fluvial;

f) 470-490: Cross bedding; well sorted; medium to coarse sand; fluvial

g) 490-510: Clay; fluvial.

h) 510-545; Cross bedding; moderately sorted; medium to coarse sand with few pebbles; fluvial

i) 545-560: Clay; fluvial;

j) 560-595: Cross bedding; well sorted; medium to coarse sand; few grind lenses; fluvial

k) 595-610: Clay; fluvial;

Profile description FF2

Date/season	: 10/7/91, middle of the rainy season
Author	: Frank van Ruitenbeek
Location	: Rio Puerto Viejo
Coordinates	: 200m north of FF1
Type	: road cut, 6m deep
Elevation	: 60m
Landform	
-physiography	: top of small hill
-topography	: hilly
-slope	: flat
Vegetation	: small bushes and palmito
Climate	: humic tropics
Geology	: pleistocene fluvial deposits
Drainage class	: lwell drained
Moisture conditions	: moist
Depth groundwater table	: > 6m
Rock outcrops	: nil
Evidence of erosion	: nil
Presence of salts or alkali	: nil
Human influence	: deforestation

Characteristics: 6m deep road cut, situated in a red hill, consinsing of relatively coarse fluvial deposites with clearly visible crossbedding.

Horizons:

a) 0-150: Yellowish brown (10YR 4/4); clay; friable; weak very coarse angular, blocky structure; diffuse and smooth boundary to:

b) 150-240: Yellowish brown (10YR 3/6); few white mottles; sandy clay; firm; few rounded pebbles (< 3cm); abrupt and wavy boundary to:

c) 240-300: Dark yellowish brown (10YR 3/6); very poorly sorted, clay to coarse pebbles (< 15cm), partly cemented; rounded pebbles (50%) touch each other; clear, wavy boundary to:

d) 300-330: Yellowish brown (10YR 5/6); rounded, medium to very coarse sand (< 0.5cm); weakly cemented; cross lamination; abrupt and wavy boundary to:

e) 330-340: Dark yellish brown (10YR 4/4); pebble-rich (<2cm, rounded); weakly cemented with orange yellow sesquioxides; clear and wavy boundary to:

f) 340-420: Yellowish brown (10YR 5/6); hardly weathered, fine to very coarse sand; few moderately rounded pebbles (< 2cm); coating of sesquioxides along the layers; weakly cemented; few black concretions; cross lamination; abrupt and wavy boundary to:

g) 420-425: Black, strongly cemented layer, containing pebbles (< 2cm); abrupt and wavy boundary to:

h) 425-440: Dark yellish brown (10YR 3/4); loamy clay; firm; few white small concretions; clear and wavy boundary to:

i) 440-520: Dark yellowish brown (10YR 4/6); fine-coarse sand; partly strongly cemented with sesquioxides; contains few brown clay layers (< 4cm) and gravel, with pebbles to 2cm; cross lamination; gradual and wavy boundary to:

j) 520-570: Dark yellowish brown (10YR 4/6); hardly weathered, fine to medium sand; partly cemented with sesquioxides; weak cross lamination; contains brown sand (!!)(10YR 3/4).

Profile FF2:

a) 0-150: Soil

b) 150-240: Moderately sorted; sand with few pebbles (<3cm); fluvial

c) 240-300: Poorly sorted; coarse grained with many pebbles (<15cm); fluvial; stream bedding

d) 300-330: Cross bedding; moderately sorted; medium to very coarse sand; fluvial

e) 330-340: Pebbles (<2cm); fluvial; stream bedding

f) 340-420: Cross bedding; moderately sorted; fine to coarse sand; fluvial

g) 420-425: Small pebbles; fluvial; stream bedding

h) 425-440: Clay; fluvial;

i) 440-520: Cross bedding; moderately sorted; fine to coarse sand; few clay lenses; fluvial

j) 520-570: Cross bedding; well sorted; fine to medium sand; fluvial

Profile description FF2

Date/season	: 10/7/91, middle of the rainy season
Author	: Frank van Ruitenbeek
Location	: Rio Puerto Viejo
Coordinates	: 200m north of FF1
Type	: road cut, 6m deep
Elevation	: 60m
Landform	:
Physiography	: top of small hill
Topography	: hilly
Slope	: flat
Vegetation	: small bushes and palmito
Climate	: humic tropics
Geology	: pleistocene fluvial deposits
Drainage class	: 1well drained
Moisture conditions	: moist
Depth groundwater table	: > 6m
Rock outcrops	: nil
Evidence of erosion	: nil
Presence of salts or alkali	: nil
Human influence	: deforestation

Characteristics: 6m deep road cut, situated in a red hill, consinsing of relatively coarse fluvial deposites with clearly visible crossbedding.

Horizons:

a) 0-150: Yellowish brown (10YR 4/4); clay; friable; weak very coarse angular, blocky structure; diffuse and smooth boundary to:

b) 150-240: Yellowish brown (10YR 3/6); few white mottles; sandy clay; firm; few rounded pebbles (<< 3cm); abrupt and wavy boundary to:

c) 240-300: Dark yellowish brown (10YR 3/6); very poorly sorted, clay to coarse pebbles (<< 15cm), partly cemented; rounded pebbles (50%) touch each other; clear, wavy boundary to:

d) 300-330: Yellowish brown (10YR 5/6); rounded, medium to very coarse sand (<< 0.5cm); weakly cemented; cross lamination; abrupt and wavy boundary to:

e) 330-340: Dark yellish brown (10YR 4/4); pebble-rich (<2cm, rounded); weakly cemented with orange yellow sesquioxides; clear and wavy boundary to:

f) 340-420: Yellowish brown (10YR 5/6); hardly weathered, fine to very coarse sand; few moderately rounded pebbles (<< 2cm); coating of sesquioxides along the layers; weakly cemented; few black concretions; cross lamination; abrupt and wavy boundary to:

g) 420-425: Black, strongly cemented layer, containing pebbles (<< 2cm); abrupt and wavy boundary to:

h) 425-440: Dark yellish brown (10YR 3/4); loamy clay; firm; few white small concretions; clear and wavy boundary to:

i) 440-520: Dark yellowish brown (10YR 4/6); fine-coarse sand; partly strongly cemented with sesquioxides; contains few brown clay layers (<< 4cm) and gravel, with pebbles to 2cm; cross lamination; gradual and wavy boundary to:

j) 520-570: Dark yellowish brown (10YR 4/6); hardly weathered, fine to medium sand; partly cemented with sesquioxides; weak cross lamination; contains brown sand (!!)(10YR 3/4).

Profile FF2:

a) 0-150: Soil

b) 150-240: Moderately sorted; sand with few pebbles (<3cm); fluvial

c) 240-300: Poorly sorted; coarse grained with many pebbles (<15cm); fluvial; stream bedding

d) 300-330: Cross bedding; moderately sorted; medium to very coarse sand; fluvial

e) 330-340: Pebbles (<2cm); fluvial; stream bedding

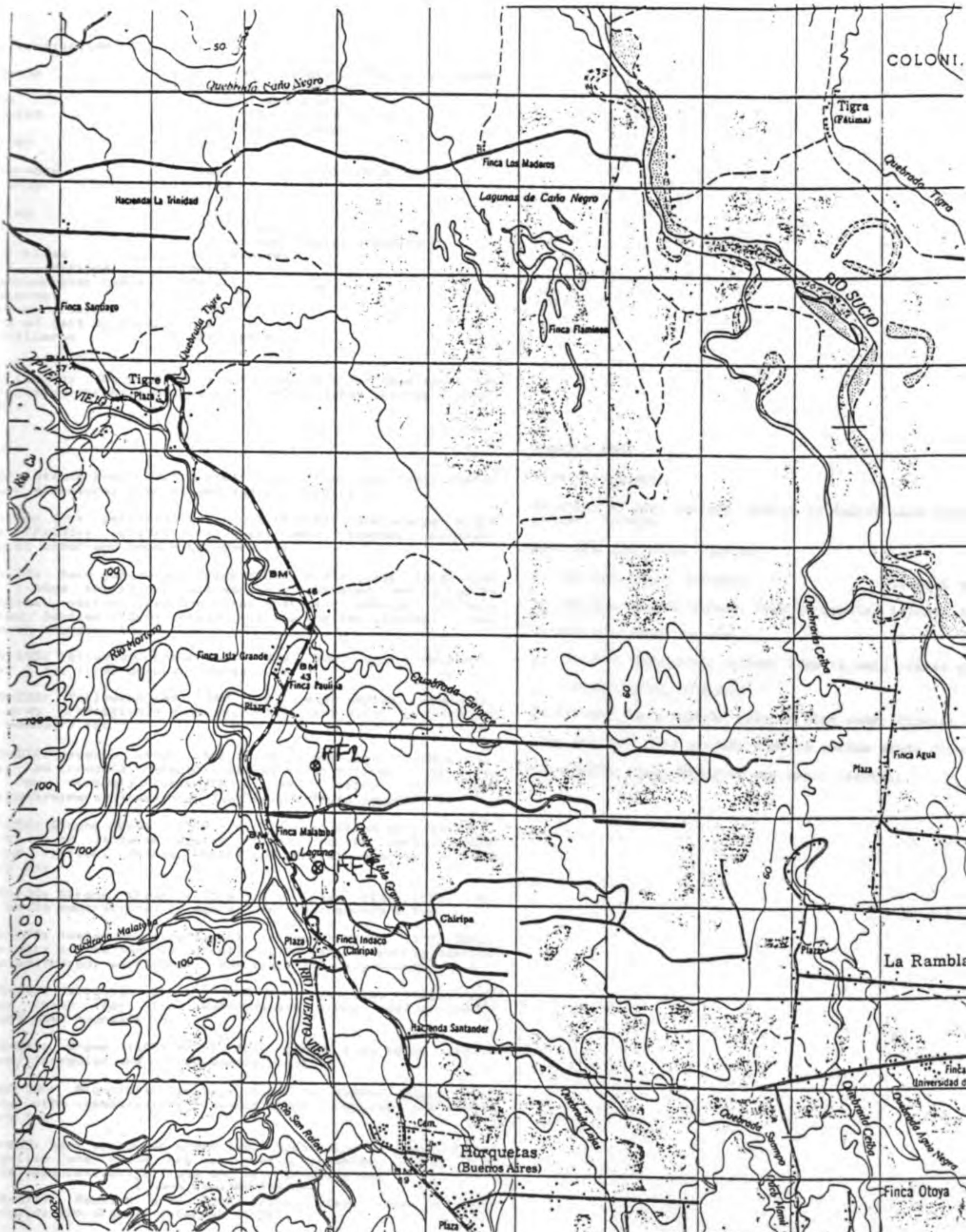
f) 340-420: Cross bedding; moderately sorted; fine to coarse sand; fluvial

g) 420-425: Small pebbles; fluvial; stream bedding

h) 425-440: Clay; fluvial;

i) 440-520: Cross bedding; moderately sorted; fine to coarse sand; few clay lenses; fluvial

j) 520-570: Cross bedding; well sorted; fine to medium sand; fluvial



Location of the Río Frío Uno (FF1) and the Río Frío Dos Profile (FF2), part of the map 'Río Sucio'

ile description FS3

season	: 17/7/1991, middle of the rainy season
or	: Frank van Ruitenbeek
tion	: canal at Rio Suerte
rdinates	: 267000/560000, Rio Sucio
	: canal cut, 7m deep
ation	: 50m
form	
siography	: middle in slope of small hill
grahpy	: hilly
e	: gently
tation	: grass
ate	: humic tropics
ogy	: pleistocene fluvial deposits
age class	: well drained
ure conditions	: moist
groundwater table	: 7m
outcrops	: nil
nce of erosion	: nil
nce of salt or alkali	: nil
influence	: deforestation

teristics: The profile is situated in a 7m deep canal cut consist of strongly weathered fine to coarse grained fluvial sits.

zons:

0-60: Strong brown (7.5YR 4/6); clay; firm; weak, very coarse nulair structure; gradual and smooth boundary to:

60-130: Dark yellowish brown (10YR 5/4); few orange brown tles (Fe2O3); clay; firm; very weak coarse, granulair ctures; clear and smooth boundary to:

30-170: Dark yellowish brown (10YR 4/4); clay; firm; with es (<10cm thick) of well sorted, weathered, medium/coarse d (black, yellow, red and grey graines); angular, strongly thered, pebbles (<3cm) (green, yellow and red cloured); clear smooth boundary to:

170-185: Yellowish brown (10YR 5/8); few, grey (reduction) tles; clay; firm; gradual and wavy to:

185-225: Yellowish red (5YR 5/6); many medium, distinct, r, grey (reduction?) mottles; clay; very firm; diffuse and oth boundary to:

225-270: Reddish brown (5YR 4/4); common grey (reduction) tles; few irregulair shaped yellish brown mottles; clay; very m; few strongly weathered, red, yellow and white crations/mineral fragments (2mm-3cm); diffuse boundary to:

270-350: Strong brown (7.5YR 4/6); few reduction mottles (270-): clay to (angular)pebbles (<2cm); poorly sorted; many thered (yellow, orange, black and white) grains; diffuse ndary to:

350-420: Strong brown (7.5YR 4/6); loamy clay; firm; few l, white concretions; irregular and clear boundary to:

420-475: (water bearing layer) Yellowish brown (10YR 5/4); to very coarse sand (< 1.5cm) in clay matrix; poorly sorted; nly weathered; weakly cemented; clear and wavy boundary to:

475-525: Yellowish brown (10YR 5/4); few grey (reduction) tles; loamy clay; firm; sesquioxides along root channels; rp and wavy boundary to:

525-560: Brown (10YR 4/3); fine sandy clay loam; weakly ented; irregular and broken boundary to:

560-580: Brown/black/yellow; fine to medium sand; very ongly with sesquioxides cemented pan; irregular and broken ndary to:

580-650: Dark yellowish brown (10YR 3/4); fine to medium sand; , yellow and cream grains; weakly cemented; along root nnels sesquioxides; diffuse and wavy boundary to:
cross + horizontal lamin.

650-670: Reddish gray (5YR 5/2); clay; very friable, otropic; few organic material (< 5%)

Profile FS3:

a/b) 0-130: Soil

c) 130-170: Well sorted; medium to coarse sand with few pebble (<3cm); fluvial

d/e) 170-225: Clay; fluvial;

f) 225-270: Clay; fluvial; gradual to:

g) 270-350: Poorly sorted; sand to pebbles (<2cm); fluvial

h) 350-420: Clay; fluvial;

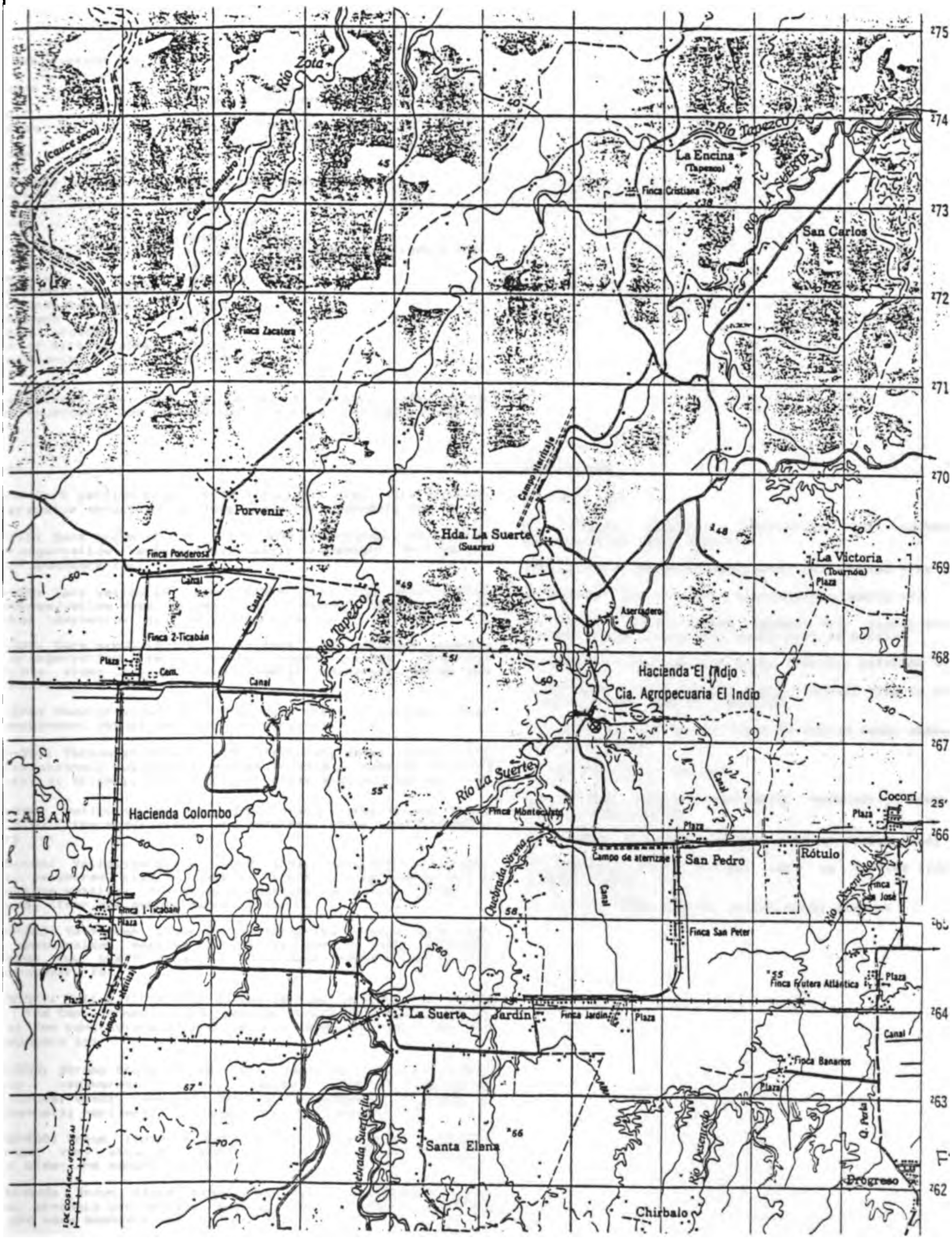
i) 420-475: Moderately sorted; fine to very coarse sand; fluvial

j) 475-525: Clay; fluvial;

k) 525-560: Well sorted; silt to fine sand; fluvial

l/m) 560-650: Well sorted; fine to medium sand; fluvial

n) 650-670: Clay; contains org.mat.; fluvial;



Location of the Río Sucio Profile (FS3), part of the map 'Río Sucio'.

ile Description FN4

season	: 22/7/91, middle of the rainy season
or	: Frank van Puitenbeek
ion	: Neguev, Rio Peje
dinates	: 588000/238000, Bonilla
	: road cut, 7 m. deep
ation	: 30 m.
form	
iography	: middle part slope of hill
graphy	: hilly
e	: gently
tation	: grassland
te	: humic tropics
gy	: probably pleistocene pyroclastic and fluvial deposits
age class	: well drained
ture conditions soil	: moist
groundwater table	: > 7m.
outcrops	: nil
nce of erosion	: nil
nce of salt or alkali	: nil
influence	: deforestation

acteristics: The soil is formed in partly, very coarse rial (mudflow?) and is situated in a road cut near the river .

izons:

0-60: Dark yellowish brown (10YR 3/4); silt/clay; very friable; se granular structure; diffuse and smooth boundary to:

60-115: Dark brown (7.5YR 3/4); fine to coarse sand; coated orange/yellow sesquioxides; weakly cemented; diffuse and gular boundary to:

115-180: Dark yellowish brown (7.5YR 3/4); fine sand; coated orange/yellow sesquioxides; very strongly cemented; fine izontal lamination; diffuse boundary to:

180-200: Dark brown (7.5YR 3/4); fine sand; strongly cemented orange/yellow sesquioxides; common black manganese crations along cracks; fine horizontal lamination; abrupt and th boundary to:

200-270: Reddish brown (5YR 4/4); silt (clay at bottom); firm; homogenous; abrupt and wavy boundary to:

270-365: Yellowish brown (10YR 5/4); very poorly sorted clay oarse strongly weathered pebbles (< 15cm); pebbles float in matrix; slightly fining upward; clear and wavy boundary to:

365-390: Yellowish red (5YR 5/6) clay ;firm; strong brown YR 4/6) fine sand; mixed and deformed; clear and irregular dary to:

390-460: Yellowish brown (10YR 5/4); very poorly sorted, ngly weathered clay to pebbles (< 5cm.); few orange/yellow uioxides mottles; fining up; contains some small layers of sand; clear and smooth boundary to:

460-525: Yellowish brown (10YR 5/4); few orange/yellow and k sesquioxides mottles; fine to medium sand strongly thered; few small pebble-rich (<1.5cm) layers; abrupt and th boundary to:

525-545: Yellow (10YR 7/6) at the bottom, strong brown (7.5YR) at the top; common white greyish reduction mottles; clay; ble; few concrations of orange/yellow sesquioxides; clear and y boundary to:

545-595: Strong brown (7.5YR 4/6); coarse sand in clay matrix; ongly weathered; partly coated with orange/yellow quioxides; weakly cemented; few black manganese concrations at t channels; horizontal laminated; diffuse boundary to:

595-630: Brown (10YR 4/3); fine to medium sand; strongly thered; very strongly cemented; very few lithic fragments cm); clear and smooth boundary to:

630-645: Brown (10YR 5/3); fine sand to pebbles (<3cm, nded, strongly weathered); poorly sorted; strongly cemented; ar and wavy boundary to:

645-670: Dark yellish brown (10RY 4/4); clayish medium sand; ongly weathered; strongly cemented; few large, soft, sferical, ck manganese concrations.

Profile FN4:

a) 0-60: Soil

b) 60-115: Parallel lamination; well sorted; fine t medium/coarse sand; fluvial

c/d) 115-200: Parallel laminated; well sorted fine sand; fluvial

e) 200-270: Clay to silt; fluvial/pyroclastic (?)

f) 270-365: Weakly fining upward; very poorly sorted; clay t pebbles (<15cm); fluvial; outer part of mudflow

g) 365-390: Clay and fine sand; fluvial; deformed dy mudflow

h) 390-460: Fining upward; poorly sorted; clay to pebbles (<5cm) fluvial; outer part of a mudflow

i) 460-525: Well sorted; fine to medium sand; contains few grin lenses; fluvial

j) 525-545: Clay; fluvial;

k) 545-595: Parallel laminated; moderately sorted; medium t coarse sand; fluvial

l) 595-630: Moderately sorted; fine to medium sand; fluvial

m) 630-645: Poorly sorted; sand to pebbles (<3cm); fluvial stream bedding

n) 645-670: Well sorted; medium sand; fluvial

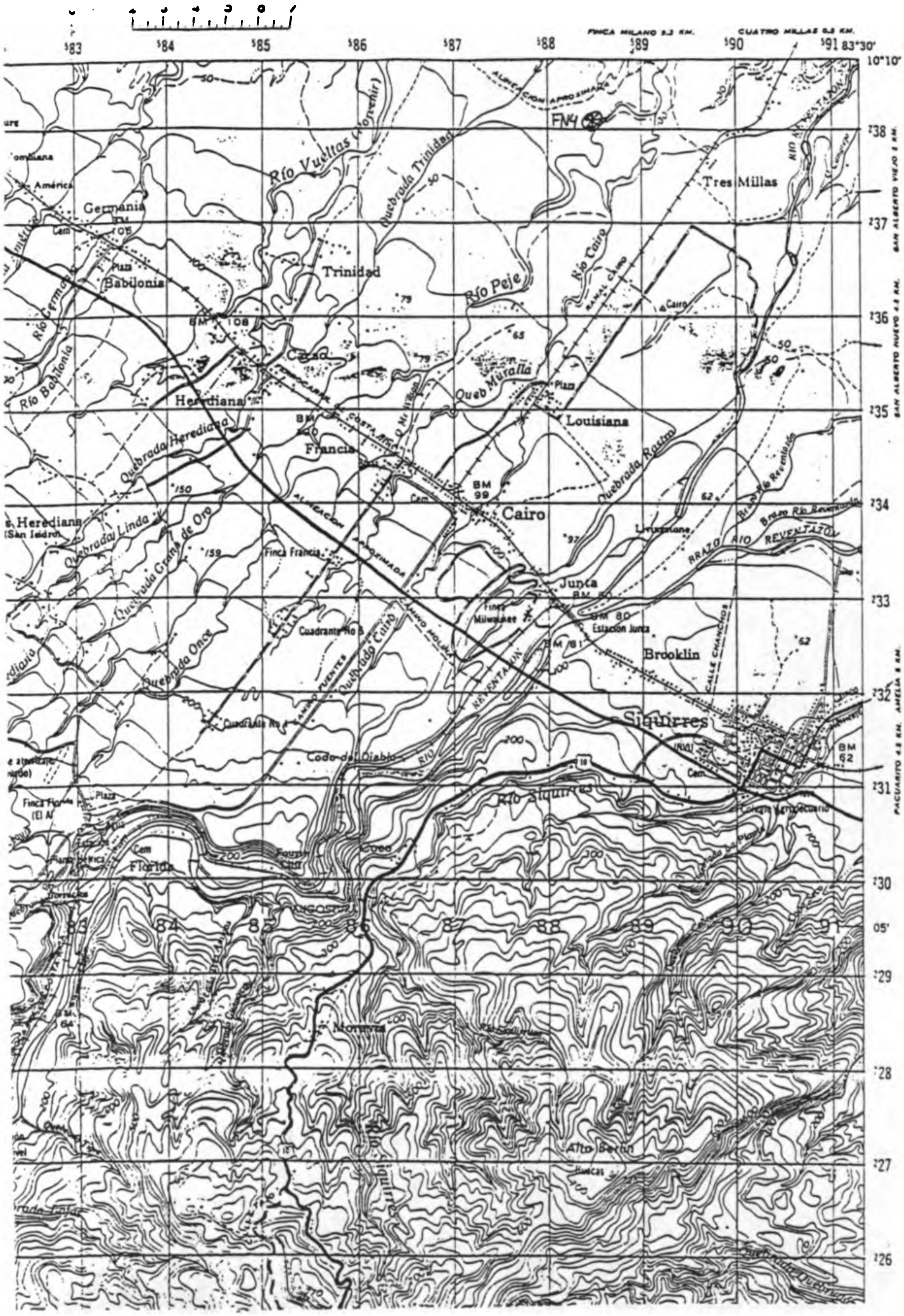
APPENDIX 3

Soil analysis:

Of each profile a mixed soil sample was taken at 25-50 cm depth:

	Ca Meq/100g	Mg Meq/100g	K Meq/100g	Na ?	O.M. Wgt.%
FF1	1.9	5.0	0.3	48	0.3
FF2	2.3	5.1	0.2	29	0.2
FS3	1.9	5.2	0.1	41	0.2
FN4	0.6	2.0	0.1	35	0.2

tabel: Soil analysis, FF1= Río Frío Uno Profile, FF2= Río Frío Dos Profile, FS3= Río Sucio Profile, FN4= Neguev Profile. O.M.= Organic matter.



Location of the Neguev Profile (FN4), part of the map 'Bonilla'.